HOW TO OBSERVE.

GEOLOGY.

BY

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WITH AN HUNDRED AND THIRTY-EIGHT WOOD-CUTS.

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ADVERTISEMENT.

"Half a word fixed upon, or near the spot, is worth a cart-load of recollection."—GRAY.

SIR JOHN HERSCHEL, in his Discourse on the study of Natural Philosophy, remarks that "to make a perfect observer in any science, an extensive acquaintance is requisite not only with the particular science to which the observations relate, but also with every branch of knowledge which may enable him to appreciate the effects of extraneous and disturbing causes. Yet," he continues, "there is scarcely any well-informed person who, if he has but the will, has not also the power to add something essential to the general stock of knowledge, if he will only observe regularly and methodically some particular class of facts, which may most excite his attention, or which his situation may best enable him to study with effect. To instance one or two subjects which *can* only be effectually improved by the united observations of great numbers widely dispersed :—Meteorology, one of the most complicated but important branches of science,

is at the same time one in which any person who will attend to plain rules, and bestow the necessary degree of attention, may do effectual service. What benefits has not geology reaped from the activity of industrious individuals, who, setting aside all theoretical views, have been content to exercise the useful and highly entertaining task of collecting specimens from the countries which they visit? In short, there is no branch of science whatever, in which at least, if useful and sensible queries were distinctly proposed, an immense mass of valuable information might not be collected from those who, in their various lines of life at home or abroad, stationary or in travel, would gladly avail themselves of opportunities of being useful."

These remarks, which gave rise to the idea of a work to be entitled "How to Observe," afford a sufficient indication of its object.

As yet, little has been done towards furnishing detailed instructions to observers. The chief exception to this remark which occurs to us is supplied in the directions contained in Mr. Babbage's admirable work on the Economy of Manufactures. The advantages and pleasures to be derived from accurate observation have indeed been often pointed out; and nowhere have they been better enforced than in the admirable tale of "*Eyes and no Eyes*" in "*Evenings at Home.*" Perhaps, however, the best mode of exciting the love of observation is, by teaching "How to Observe." With this end it was originally intended to produce, in one or two volumes, a series of hints for travellers and students, calling their attention to the points necessary for inquiry or observation in the different branches

of Geology, Natural History, Agriculture, the Fine Arts, General Statistics, and Social Manners. On consideration, however, it was determined somewhat to extend the plan, and to separate the great divisions of the field of observation, so that those whose tastes led them to one particular branch of inquiry might not be encumbered with other parts in which they do not feel an equal interest. Thus, the present Volume on Geology is complete in itself, although contained in the general plan of the series.

It is hoped, that whilst "How to Observe" will afford assistance to the scientific traveller and student, it will also be the means of inducing others to collect information on all or some of the heads noticed. Thus the listless idler may be changed into an inquiring and useful observer, and may acquire the power of converting a dull and dreary road into a district teeming with interest and pleasure. To acquire this power, it is not necessary that the observer should be profoundly skilled in all the subjects that come under his observation. He may soon acquire sufficient knowledge to appreciate what he sees, and to express what he feels. The charm that such habits of observation bestow upon the descriptions of the commonest things is evident in those works in which the observer expresses what he has seen with his own eyes simply and correctly. What reader is there who has not risen with delight from every fresh perusal of White's Natural History of Selborne, a work at once showing the importance of accurate and detailed observation, and the small quantity of scientific knowledge requisite to produce that which is both valuable and interesting. On the other

hand, the writings of St. Pierre, abounding with eloquence and picturesque descriptions, are now nearly forgotten, because they are wanting in that accuracy and minute observation which alone can command a lasting interest.

H. B. K.

London, June 1st, 1835.

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HOW TO OBSERVE.

GEOLOGY.

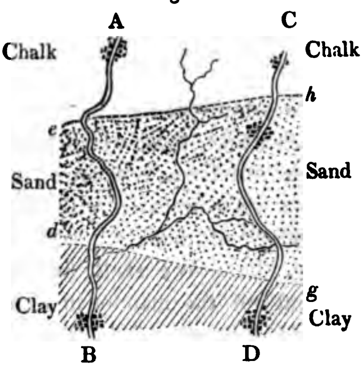
PART I.

Geological observations may be conveniently classed under two heads: first, those which bear immediately on Geology viewed strictly as a science; and secondly, those which show its connexion with the various necessities and comforts of mankind, such as agriculture, mining, building, &c. We shall, in the first place, endeavour to point out the manner in which those who desire to advance the science of Geology may effectively do so, though they may as yet be little acquainted with it, and then proceed to consider the second class of observations, which have, in general, been too much neglected.

There are probably few so little observant of natural objects as not to have remarked that the appearances of countries differed materially according to their soils, and that these again were connected with the kinds of mineral substances found beneath them, such as sands, clays, and various kinds of solid rock. It must also have been observed, while travelling in particular directions over lines of country not far removed from each other, that a succession of similar kinds of soil

or rock frequently occurred; so that if the points where the various changes took place in the different roads were marked upon a map, and that lines were drawn from point to point where the same changes of soil or rock were observed, certain portions of country would be marked off in which the same kind of soil or rock would prevail.

Fig. 1.



Let us suppose that a traveller takes his course from B to A by the road B A, and that the town or village B stands upon clay which he finds is continued to *d*, where sand forms the soil and rock of the country. The traveller would probably class the country he has passed over among the clay districts. Let us further suppose that the same observer, in the prosecution of his journey, finds the sandy country to end at *e*, after which chalk forms the rock to the termination of his journey at A. The traveller would scarcely fail to consider the district he has traversed as composed, in succession, of clay, sands, and chalk; but he would still

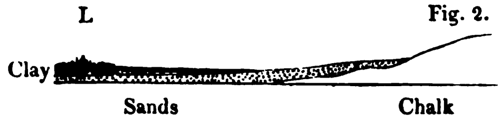
be unacquainted with the direction taken by any of these kinds of country.

Let us now consider that the same traveller had occasion to pass over another road, D C, to a certain extent parallel to the former, B A, but distant from it a few miles, and that he found a clay at D, similar to that on which B is situated. Our observer would now most probably conclude that the clayey country of B extended to D. If in the progress of his journey the traveller quits the clay at *g*, and finds the same kind of sandy rock and soil that he had previously observed at *d* on the road B A, and further if at *h* he enters upon the same kind of chalky country that he found at *e* on the other road, he might be induced to draw lines on his map from *d* to *g*, and from *e* to *h*, which would thus divide the portion of country included between the roads B A and D C into three parts—one clayey, another sandy, and the third chalky.

Having advanced thus far in what may be considered a rude attempt at a geological map, the observer may probably infer that there is something like a succession of mineral substances in this part of the country, and be induced to travel over other portions of the district, to the right and left of those he has thus noticed, to see if the same kind of succession continued in those directions; and finding this, he might conclude that soils, or rather the rocks or mineral substances whence they are principally derived, are not confusedly mixed up with each other, but that they occur in a certain order of succession, viewing the subject more generally. Having arrived at this conclusion, his next step would probably be to ascertain whether these mineral sub-

stances or rocks rested upon each other; and if so, their relative order of superposition. We will suppose, for the sake of illustration, that he finds the clay, as seen in the annexed section,* Fig. 2, to rest upon the

Fig. 2.



sands, and these again on the chalk. Having clearly ascertained this fact in several places, he could not be otherwise than convinced that, in the district examined, these mineral substances or rocks succeeded each other in the order represented in the section, which may at the same time afford a rough idea of the geological structure of the country near London, the clay being termed the 'London clay,' because the metropolis (L) stands upon it, beneath which are certain sands interstratified with clays (named plastic because used in pottery) that in their turn repose upon chalk, which rises in hills at various distances to the S., W., and N. of the metropolis.

* A geological section is considered to be vertical, unless otherwise stated. Like other sections, it is supposed to be some material thing divided; so that one part being removed, the structure of the other part is well seen. Thus, when we divide an orange or an apple, we make a section which exposes their interior structure, which is otherwise concealed. Some geological sections are natural, such as those afforded by sea-cliffs; some are artificial, such as deep cuts for roads and other purposes; while others are ideal, like that in the text, being constructed from the knowledge of various facts which render them either highly probable or almost certain,—it, of course, being understood that all possible care has been used in their construction.

Having, from these simple observations, ascertained that some rocks at least succeed each other in a certain order, an intelligent person would probably have his curiosity so far stimulated as to inquire whether other observers have remarked similar successions of rocks in other districts and countries. Finding that the subject had long engaged the attention of several other persons, he would naturally be anxious to learn the conclusions they had deduced from their observations, as also 'how to observe' any facts he may chance to meet with, in order that he should obtain not only a general idea of existing knowledge on the subject, but also the power of employing his time to the best advantage by not sacrificing it in observing things of little or no importance. It is our object to afford this general idea of the present state of geology, with directions to the traveller and student 'how to observe,' so that their labour may not be thrown away; trusting also that some few who may peruse these pages and who have not hitherto attended to the subject, may be induced to observe and record facts that may advance the science, and which might otherwise be passed unnoticed.

The researches of Geologists have taught them that the rocks* which constitute the visible solid surface of our earth have either been deposited from water where, for the time, the substances of which they are composed

* The term 'rock' is applied by Geologists to all kinds of coherent mineral masses composing the solid crust of our globe, whether they be hard or not. Thus various clays, marls, soft sandstones, and the like, are termed rocks, when they form portions of the series of mineral masses composing land. Even incoherent sands are termed rocks when they constitute a component part of a series of beds or strata.

were either chemically or mechanically suspended, or have once been in a liquid melted state from the action of heat upon them. The former are termed aqueous, and the latter igneous rocks, from the nature of their origin. Rocks are also classed under the heads of 'stratified' and 'unstratified;' terms considered synonymous with 'aqueous' and 'igneous.' There are objections to these terms, as will be perceived in the sequel; but as they do not outbalance their convenience in the present state of geology, we shall employ those of 'stratified' and 'unstratified,' as is now mostly commonly done.

When rocks are divided into beds like the leaves of a book, or several books or pieces of cloth piled upon each other, they are said to be stratified. When an

Fig. 3.

observer finds a series of beds resting upon each other as represented in the cliffs, Fig. 3, he has before him a rock or rocks said to be stratified. It is, however, by no means necessary that the rocks should be divided into beds as flat as the leaves of a book, or as pieces of cloth laid upon each other, to entitle them to the term

stratified. Such beds as those represented in the annexed sketch (Fig. 4) would still be termed strati-

fied. When no traces of beds can be detected, and the rock merely forms a great mass of mineral matter, without other lines than those of cleavage, to be noticed hereafter, it is said to be unstratified. Such rocks have frequently the heavy lumpy character represented beneath (Fig. 5).

The stratified rocks are divided into two classes, the 'fossiliferous' and the 'non-fossiliferous;' the former containing the remains of animals and plants which have once existed, and whose exuviæ, found in various states of preservation and mineralization, are commonly termed fossils or organic remains, while the latter afford no traces of such exuviæ. These terms are applied to the rocks in question as masses; for though the non-fossiliferous rocks are never found to contain organic remains, many beds among the fossiliferous are also without such exuviæ, and might therefore, as far as regarded themselves, be termed non-fossiliferous; but being associated as the bed *c* (Fig. 6) is with *a*, *b*, *d*,

Fig. 6.

and *e*, organic remains being detected in the latter, while they are not found in the bed *c*, they are necessarily included among the fossiliferous class, the absence of fossils being accidental and due to particular circumstances.

The non-fossiliferous rocks are also known by the name of 'primary,' because they are the lowest stratified rocks with which we are acquainted, and hence are considered to have been first formed. Among them

we observe facts which render it necessary that we should, in the true spirit of philosophical inquiry, be extremely cautious in supposing that all beds of mineral matter, or stratified rocks, have been deposited from water. It is not our intention to enter into a discussion on this head, referring to the various treatises on geology for information on the subject; but we mention it to guard the reader from a too ready acquiescence in the belief that all rocks divided into beds, or stratified, particularly among the non-fossiliferous class, are necessarily of aqueous origin.

The non-fossiliferous rocks are for the most part formed of a mixture of a few minerals, the most important of which are quartz, felspar (common and compact) hornblende, mica, schorl, garnet, chlorite, talc, and steatite. A great variety of others occasionally enter into their composition; and one, carbonate of lime, sometimes constitutes whole associated rocks, most frequently in the form of statuary marble. It rarely happens that these rocks are not crystalline or subcrystalline. For the most part they form confused mixtures of two, three, or more of these minerals; and are then known, according to the particular mixture, by different names,—such as *gneiss*, *mica slate*, *talcose slate*, *hornblende rocks*, &c. For particular descriptions of these rocks we must refer to treatises on geology; recommending the reader, if unacquainted with the subject, to dedicate a short time in some good cabinet or museum to the study of the rocks in question, in company with a competent person, by which he will learn more in a few hours than in weeks spent in the mere perusal of descriptions. It may however be remarked, that, viewed chemically, the non-fossiliferous rocks constitute

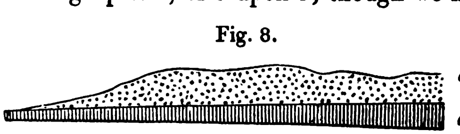
a mass of silicates, among which carbonates are very sparingly disseminated. The principal silicates are those of alumina, potash, soda, magnesia, and lime; and the carbonates, those of lime and magnesia. Silica is the chief ingredient, alumina the next important substance; and then follow potash, magnesia, and soda. Lime and fluoric acid are extensively disseminated in small quantities, and the oxides of iron and manganese are also common, the former greatly predominating.

Upon these repose the fossiliferous rocks; and in them we have evidence that animal and vegetable life existed on our planet before such rocks were formed, since their remains are detected in them. Among the members of the non-fossiliferous class it cannot be said that any particular order of superposition is observable; though, viewed in the mass, the particular mineral compounds named gneiss and mica slate may be said to prevail in its lowest parts. With the fossiliferous rocks, however, the case is different: among them we find a certain order of superposition which has never been found inverted; that is to say, if the order be that

Fig. 7.

of *a*, *b*, *c*, *d*, in the annexed section (Fig. 7), we never find *d* resting upon *a*, or *c* upon *b*, though we may find

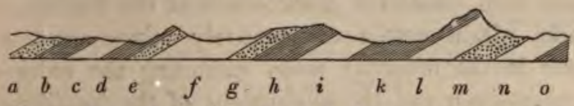
Fig. 8.



a resting upon *d*, as above (Fig. 8), either from *b* and *c* never having been formed in that particular situation, or, having been so, they were swept away before the production of *a*, which would necessarily cause *a* to rest immediately upon *d*.

When we state that a given order of superposition reigns among the fossiliferous rocks, it must not be understood that particular mineral compounds are not repeated in the series; for in fact they are so repeated, various sandstones, clays, and limestones often differing slightly, if at all, from each other, following no more order as mineral substances than the non-fossiliferous rocks noticed above. By a given order of superposition among the fossiliferous rocks, we mean that certain masses of mineral substances, no matter what kind of mineral substances they may be, have been produced at distinct geological periods, one after the other; and that, as far as researches have yet extended in Europe, where they have been most studied, they contain, as masses, certain assemblages of organic remains not detected in the others. That is, if, for the sake of illustration, we suppose a series of fossiliferous

Fig. 9.



rocks, *a*, *b*, *c*, *d*, *e*, *f*, *g*, *h*, *i*, *k*, *l*, *m*, *n*, *o*, to rest upon one another as in the above diagram, (though it must not be supposed that such a number of fossiliferous rocks ever succeed each other in nature with such perfect regularity and parallelism,) each would contain

organic remains differing as a whole from those discovered in the others, either above or beneath it; though *a, e, g, m,* may be sandstones; *b, d, h, k, o,* shales or clays; and *c, f, i, l, n,* limestones.

The fossiliferous rocks have, for convenience, been arranged in groups bearing various names, which in general show the countries where each group has been more particularly studied or developed. As these rocks are chiefly of mechanical origin, though many are evidently precipitates from chemical solutions, it cannot be expected that any great uniformity of mineral structure should be observed over very extended areas, far less that we should find the same mineral composition in rocks of equal age over the face of the globe:—unless, indeed, we suppose equal circumstances to obtain over the whole superficies of our planet at the same times; which would evidently be an absurdity, when rocks of mechanical origin are concerned, or those derived by aqueous abrasion from pre-existing rocks, and which are deposits from water in which their component parts have been mechanically suspended. In order, however, to enable the reader to become acquainted with those mineralogical compositions which have been considered characteristic of the fossiliferous rocks within certain comparatively minor areas, we have in the following table, exhibiting the order of superposition and the subdivisions of the fossiliferous groups, given a short notice of the mineral structure of the rocks beneath the supracretaceous or tertiary beds; premising that such structures are merely characteristic of more or less limited areas, as we shall have occasion still further to insist upon.

List of the Fossiliferous Rocks of part of Western Europe, in the descending Order.

GROUP.	SUBDIVISIONS.	MINERAL STRUCTURE.
1. Modern.		Detritus of various kinds deposited from water in which it was mechanically suspended; modern calcareous, siliceous, and other chemical deposits from water; coral islands, reefs, &c.
2. Supracretaceous. *Tertiary* rocks of the improved Wernerian classification;) *superior* rocks of Conybeare.	Divided by Lyell, who retains the name *tertiary* for this group, into four subgroups; *viz.* newer pliocene, older pliocene, miocene, and eocene.	Detritus of various kinds deposited from water; calcareous, siliceous, and other deposits from chemical solutions, &c.
3. Cretaceous. (Highest of the *secondary* rocks of the improved Wernerian classification; highest of the *supermedial* rocks of Conybeare.)	*a.* Chalk.	The well-known calcareous substance so named, mixed with flints, particularly in its upper part.
	b. Upper green sand.	An arenaceous rock, for the most part very calcareous, in which green grains of silicate of iron are abundant.
	c. Gault.	An argillaceous deposit of a bluish grey colour, containing much calcareous matter.
	d. Lower green sand.	Sands and sandstones, principally of ferruginous or green colours, the latter prevailing in the lower portions.
4. Oolitic.	*a.* Portland stone.	Beds of an oolitic limestone, or roestone, associated with compact limestone beds, flint and chert.

GROUP.	SUBDIVISIONS.	MINERAL STRUCTURE.
Oolitic (*continued.*)	*b.* Portland, or Kimmeridge sands.	Calcareo-siliceous sands and concretions.
	c. Kimmeridge clay.	An argillo-calcareous deposit, sometimes carbonaceous.
	d. Upper calcareous grit.	An arenaceous deposit.
	e. Coral rag.	So named from an abundance of fossil corals generally detected in it. The oolitic limestones associated with it are sometimes of so large a grain as to be termed *pisolite.*
	f. Lower calcareous grit.	An arenaceous rock.
	g. Oxford clay.	A grey argillo-calcareous deposit, in the lower part of which a calcareous sandstone, named Kelloway rock, is often developed.
	h. Compound great oolite: including, in the descending order, 1. Cornbrash, 2. Forest marble, 3. Bradford clay, 4. Great or Bath oolite.	A series of calcareous rocks, compact, oolitic, and friable; sometimes associated with clays or marls. A rock, remarkable for its organic contents, and named Stonesfield slate, sometimes forms the base of the great oolite.
	i. Fuller's earth's.	An argillaceous deposit, so named because fuller's earth is obtained from it in some localities.
	k. Inferior oolite.	The upper part formed of calcareous beds in which grains and small nodules of hydrate of iron are abundant, while the lower part principally consists of calcareo-siliceous sands and concretions.

GROUP.	SUBDIVISIONS.	MINERAL STRUCTURE.
Oolitic *(continued.)*	*l.* Lias.	An argillo-calcareous deposit, in which beds of argillaceous limestones are frequently developed, particularly in the lower portions.
5. Red sandstone.	*a.* Variegated or red marl.	Marls of various tints of red, blue, grey, green, and white; the former greatly predominating. Gypsum is frequently found in them, and rock salt is occasionally detected.
	b. Muschelkalk.	Limestone beds of variable texture, but most frequently grey and compact. This rock is occasionally dolomitic.
	c. Red or variegated sandstone.	An arenaceous deposit, principally argillaceous and siliceous, of various tints of green, white, blue, and red; the latter greatly predominating. Occasionally contains masses of gypsum and rock salt.
	d. Zechstein, or magnesian limestone.	Limestone beds, in which carbonate of magnesia is disseminated in variable quantities, so that the rock sometimes becomes the crystalline compound of the carbonates of magnesia and lime named *dolomite.* The whole rests upon a marl slate, named *kupferschiefer*, because it contains copper in Germany.
	e. Rothliegendes.	A series of red sandstones and conglomerates, occasionally intermingled with red marls or clays. In some situations the sandstones prevail; in the others, the conglomerates; the latter generally occupying the lower parts.

GROUP.	SUBDIVISIONS.	MINERAL STRUCTURE.
6. Carboniferous. (The authors who employ the improved Wernerian classification vary in this part of the series. Some commence the *transition* rocks with *a*, others with *b*, and others again with *c*.) *Medial* rocks of Conybeare.	*a*. Coal measures.	A variety of shales, sandstones, and occasionally conglomerates; among which coal-beds, differing considerably in thickness, are associated.
	b. Carboniferous limestone.	Compact limestones, for the most part of a grey tint, often sufficiently hard to be employed as marble.
	c. Old red sandstone.	A variety of sandstones, chiefly red, among which conglomerates sometimes occur, as also calcareous portions, named *cornstones*.
7. Grauwacke. . (*Transition* rocks of the Wernerian classification;—*sub-medial* rocks of Conybeare.)	. . .	A considerable accumulation of arenaceous rocks, among which conglomerates occasionally occur. It is chiefly composed of argillaceous and siliceous matter, forming slates and sandstones. Limestones in exceedingly subordinate quantities occur in various parts of the series, and beds of anthracite are sometimes detected in it. Its tints are principally grey and brown, but red is here and there found in all parts of this series. The lower portions appear to graduate, principally by an increase of associated crystalline strata, into the non-fossiliferous rocks.

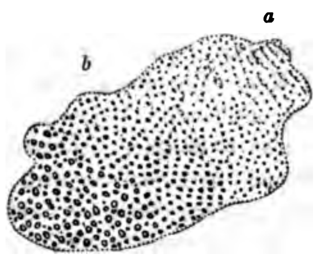
We have said that the mineral structures of the groups and their subdivisions, above noticed, could only be considered characteristic of minor areas; and we may cite in illustration, that while the compound great oolite of Somerset and Wilts is formed principally of calcareous matter enveloping a great abundance

of marine organic remains, its equivalent in Yorkshire is chiefly composed of arenaceous and shale beds with associated coal, the remains of terrestrial plants being exceedingly abundant, while marine exuviæ and the calcareous strata containing them are of a very subordinate character. Again, the old red sandstone, which in Herefordshire is an important arenaceous rock, is in the North of England represented by a conglomerate, sometimes of inconsiderable thickness. The carboniferous limestone also of Southern England, in which coal does not occur and limestone so greatly prevails, is in Northern England represented by sandstones, shales, and coal-beds, the limestone becoming to a certain degree subordinate. On the other hand, the mineralogical character of some groups, or their subdivisions, is constant, or nearly so, over considerable areas. We may cite as illustrative of this fact the well-known white chalk, which preserves its mineral character from the borders of the Sea of Azof, through part of Russia, Poland, Sweden, the northern parts of Germany, the British Islands, and in a large portion of France. Certain argillaceous portions of the oolitic group cover extensive areas, and the general mineral character of the grauwacke is remarkably similar in Europe and North America.

The reader may here demand the utility of observing the mineralogical characters of these rocks at all, since they are thus changeable. A little reflection will, however, show him that to observe these changes is particularly important, since they prove that equal circumstances have not obtained throughout the area occupied by any given group of rocks, or its subdivisions, during

the period of its or their formation, and that by noting the kind of changes which take place he may approximate towards a knowledge of the circumstances which have produced them.

Fig. 10.



Let *a*, *b*, *c*, (Fig. 10) represent an area occupied by a mechanical rock, that is, one formed of the detritus of pre-existing rocks,—an area which for the sake of illustration we may estimate equal to a thousand square miles,—a fine sandstone approaching to clay being found at *a*, coarser grained sandstone at *b*, while conglomerate is discovered at *c*, the various parts shading into each other, so that no doubt can exist that the whole is geologically contemporaneous, that is, formed at the same geological epoch. It is clear that exactly the same circumstances have not obtained over the whole area during the deposition of the rock. As, in all probability, moving water has carried the component parts of the rock into the respective situations they now occupy, we might infer that the velocity of the transporting water had varied in the different situations; for it is clear that a velocity merely sufficient, all other things

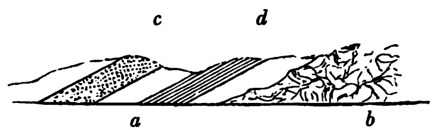
being equal, to carry the silt at *a* would be insufficient to move the coarser sand at *b*, while the larger fragments and pebbles at *c* could not be transported by the same force which would merely move the particles of sand at *b*. We might in fact infer that there was a greater intensity of moving power at *c* than at *a*, gradually decreasing from *c* to *a*; and consequently, if the same body of moving water has carried the parts of the rock to their present respective situations, that the velocity of such moving water decreased from *c* to *a*. By examining mere sandy clay, or even sand, the evidence as to the quarter whence the detritus was derived is not always satisfactory: with pebbles or fragments of rocks the case is, however, for the most part different; and we thus frequently obtain direct information as to the quarter whence they have been derived, such pebbles or fragments being portions of older rocks often visible in the district or country where the conglomerate exists. We will not here enter into the various ways in which moving water may distribute detritus, since the above remarks are merely intended to show that observations respecting the variations in structure of mechanical rocks possess considerable interest, and are highly important as respects theoretical geology.

When we find a rock crystalline and without organic remains in one part of its course, while other parts are not crystalline, perhaps even arenaceous, and replete with animal and vegetable exuviæ, it is clear that some circumstances have obtained in one part of the area not common to the whole; and if we desire to rise from a

view of the rocks themselves to the probable causes which have produced them, it is also evident that it is important to observe these differences with great care, since it is only by caution and duly weighing the evidence before us in all its bearings that we can approximate towards the truth.

In the above diagram (Fig. 10) we have supposed, for more easy illustration, that the rock was horizontal and uncovered by others: more frequently, however, rocks are not horizontal, and are covered by others over the larger portion of the areas which, we infer, are occupied by them. They are often tilted up, as in the vertical section beneath (Fig. 11), where we have sup-

Fig. 11.

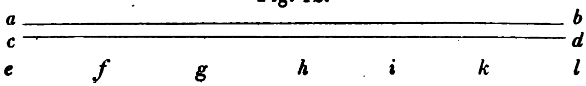


posed the stratified rock *a* to have been thrust up at one end by the protrusion of the igneous rock *b*; or they may have taken an inclination even equal to 30° or 40° when deposited.* In either of these cases variations (if there be any) in the structure of such beds as *c* or *d*, or of the general assemblage of beds composing the rock, can only be observed where the edges of the strata cut the surface of the country, or in natural or artificial vertical sections, such as ravines, quarries, &c. The lines in which such tilted or inclined beds cut the horizontal plane are termed those of *strike*

* See Researches in Theoretical Geology, by H. T. De la Beche, p. 50.

or *direction;* and by carefully observing the changes which take place in certain beds, or in the rocks generally of which they constitute the component parts, much valuable information may be obtained. To illustrate this, let us suppose that the lines *a b* and *c d*

Fig. 12.



represent the strike or direction of a highly inclined portion of the grauwacke of Southern Devon, where such changes are very common, and that the distance between the lines is about a mile. We may have an argillaceous slate at *e*, which passes into an arenaceous grauwacke at *f*, becoming a quartz rock at *g*, whence it again shades off to an arenaceous grauwacke at *h*, becoming more argillaceous at *i*, an argillaceous slate at *k*, and almost a roofing slate at *l*. From thus observing the various mineral conditions of the fossiliferous rocks, and noting the size of the respective areas in which the same mineral structure prevails, we obtain the comparative value of each condition, and consequently of the probable cause which may have produced it.

Although we should thus obtain information as to the variable forces of moving water by which abraded portions of pre-existing rocks have been deposited in new situations, and frequently of the quarters whence such detritus has been derived, as also of the relative amount of chemical products mixed with the mechanical rocks of the same geological epoch; we should

not know that any other than the existing species of animals and plants had ever lived on the surface of our planet, or that there had been successive creations of animals and plants, called into existence and destroyed as new conditions arose, either over the earth's surface, or in areas of different magnitudes. The fossiliferous rocks afford us, by their organic contents, not only this, but also much collateral information of the highest interest, as well botanical and zoological, as geological. To the botanist and zoologist naturally belongs that careful investigation of organic remains which enables them to determine their true or highly probable place among those known created things which either have possessed or now possess life; while the geologist masses the information thus derived, and combines it with the probable causes that may have produced those conditions under which inorganic matter is presented to his attention on the surface of the earth.

For information respecting the various organic remains detected in the fossiliferous rocks, we must refer to those works which profess to give lists of such as have been hitherto described.* These lists are far more full than those unacquainted with the subject might suspect, and exhibit the great practical benefit of the division of labour; for though many of these exuviæ have been brought to light by those who may be strictly termed geologists, a large proportion have been col-

* For the organic remains found in the supracretaceous group (or tertiary rocks), consult Lyell's Principles of Geology, vol. iii. 1st edition; and for those from the cretaceous to the grauwacke groups inclusive, De la Beche's Geological Manual, 3rd edition.

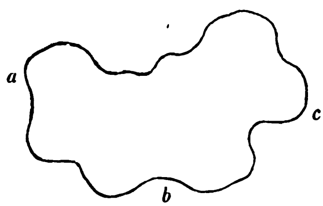
lected by persons whose acquaintance with geology, properly so called, has been limited.

It was once assumed that given assemblages of animal and vegetable exuviæ, discovered in particular rocks, would be found to characterise the mineral deposits of a given geological epoch, if not over the whole face of the globe, at least over very large portions of it. The distribution of animal and vegetable life over the surface of the earth being now so various, that no naturalist expects to find precisely the same animals and plants in localities far distant from each other, even when such localities are perfectly similar with respect to climate and other circumstances; it follows, that the supposition of given organic remains being always detected in rocks of the same geological epoch wherever such rocks may be found, is utterly at variance with the present distribution of animal and vegetable life over our planet.

Such hasty generalizations are common in the early history of most sciences, and can only be considered effectively mischievous when there is a determination to uphold them in spite of direct evidence of their unsoundness. It is more generally considered in the present day, that given organic remains are spread over larger areas, in contemporaneous rocks, in proportion to the geological antiquity of such rocks: that is, we should expect to find greater uniformity in the animal and vegetable exuviæ entombed in the grauwacke of distant localities than in the supracretaceous rocks of equally distant situations. Now it is remarkable that, as far as investigations have yet gone, there is much to support this hypothesis; but we must be careful in not

assuming it to be absolutely true until observations be greatly more multiplied than they are at present. If, however, we suppose it true, it can only be so to a certain extent; since we can scarcely imagine such complete uniformity of conditions over the globe, unmodified by local causes, as to afford exactly the same results everywhere. Moreover, we have direct evidence to adduce that the organic contents even of the more ancient rocks vary over minor areas. If the annexed

Fig. 13.



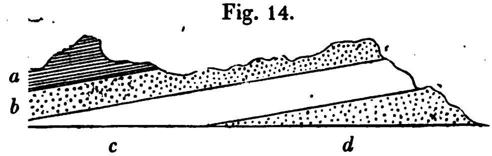
sketch (Fig. 13) represent an area of eight or ten thousand square miles occupied by some given rock, of the continuity of which, though frequently covered by more modern deposits, there exists no doubt, it rarely happens that the organic contents of such a rock would be found precisely the same at *a*, *b*, and *c*, respectively. It might so happen that marine exuviæ were alone detected at *a*, while remains indicative generally of the proximity of land were discovered at *b*, and little else than terrestrial plants were found at *c*. Independently of this change in the organic character of the deposit, we should probably also obtain a difference in its mineralogical character; the rock being per-

haps a limestone or highly calcareous at *a*, more argillaceous or clayey at *b*, while sandstones, shales, and even coal may constitute the mass at *c*.

The reader will have gathered from the preceding observations, that a combined view of the organic and mineralogical characters of the fossiliferous rocks is highly important, since we thence approximate towards a knowledge of the various causes which have attended their production. The question also of whether the ancient fossiliferous rocks are more constant in their organic characters over considerable areas than the modern, is also one of high geological interest, since, however little they may differ mineralogically from each other viewed in the mass, it is clear, if there be this difference in their organic character, there must have been some modifying circumstances at one epoch different from those at the other. It can only be by multiplied observations that this can be decided; and the power of contributing to solve this, as well as many other geological problems, is alike open to him whom these pages may induce to observe, as to those who have passed years in the study, and who, as geological pioneers, have smoothed many a rugged path for those who follow them.

When fossiliferous rocks rest *conformably* upon each other, (that is, when, as in the annexed section, a series of

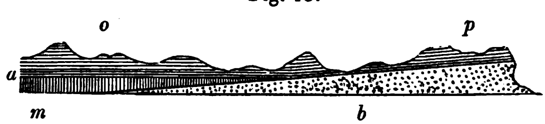
Fig. 14.



C

deposits rests upon an other in a manner which will not permit us to suppose that the lowest, *d*, has been heaved up, or otherwise disturbed, before the next above it, *c*, was formed, and so on with *b* and *a* in succession,) it is inferred that, in the situation where these rocks have been deposited, the organic exuviæ found in them are the remains of either animals or plants, as the case may be, which have succeeded each other in the same place in the order of the rocks themselves. It is not to be inferred, as has sometimes been done, that similar animals or plants succeeded each other over the whole surface of the globe; for, in the extension of a series of deposits such as that represented above (Fig. 14), in other directions other deposits may be discovered between the rocks of which it is composed, and yet, in the situation first observed, the rocks may rest as tabular masses conformably upon each other. Let us suppose that *a* and *b* (Fig. 15) represent the same rocks as *a* and *b*, Fig. 14, then *m* might be included between them at *o*, while at *p* they should appear strictly conformable, the rock *m* having *fined off*, as it is termed, in the horizontal distance between *o* and *p*;

Fig. 15.

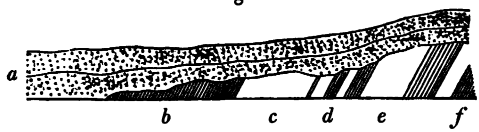


that is, its vertical thickness has decreased by degrees, so that the horizontal extension of *m* would not be so great in this situation as that of *a* and *b*. It, however, by no means follows that *m* does not cover a greater

area altogether, for it may readily do so, *a* and *b* fining off between other rocks in other directions.

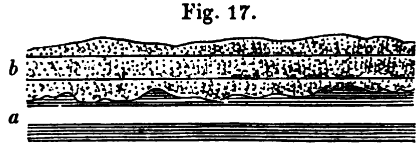
When fossiliferous rocks rest *unconformably* upon each other,—that is, when, as in the annexed section (Fig. 16), a rock, *a*, rests upon the upturned edges of

Fig. 16.



the beds *b*, *c*, *d*, *e*, *f*,—we cannot infer that the animals and plants whose exuviæ may be detected in *a* succeeded those whose remains are discovered in *b*, since many rocks may have once existed above *b*, which have been carried away by *denudation*, as it is termed; that is, removed by the abrading power of moving water before *a* was formed: and if the angle be so considerable as that represented above (Fig. 16), we should infer that the rocks *b*, *c*, *d*, *e*, *f*, were tilted up by violence before *a* was deposited. There is also another kind of superposition which may be termed *irregular*, even when the beds of two rocks in contact may, as masses, rest conformably on each other. If we find, as in the annexed section (Fig. 17), that the

Fig. 17.



upper surface of a fossiliferous rock, *a*, has been waterworn before another fossiliferous rock, *b*, was deposited

upon it, we have no evidence to show that the animals and plants existing when *a* was formed were succeeded by those whose remains are detected in *b*; other intervening deposits may have been thrown down, and subsequently swept away, after the production of *a* and before the formation of *b*.

As this is not intended for an essay on the present state of geology, we shall now briefly notice the igneous rocks, and then proceed to our more immediate object, 'how to observe.' Those rocks are termed igneous which we consider to have once been in a fluid state from the action of heat upon them, and in that state to have overflowed, to have been injected among, or to have been propelled through, other rocks.

In volcanos we have direct evidence that liquid melted rock may be heaved out of the earth by forces acting beneath, and in that state flow over those channels which offer it the least resistance, thus forming the well-known *lava currents.* When also, from a change in the volcanic vent, great natural sections are afforded of a former crater, it is sometimes found that the melted rock has risen among the layers of ashes and cinders of former eruptions, cracks having been produced in the mass of such ashes and cinders, into which the fluid melted rock has risen.

It is from similar facts being observable in the mode of occurrence of other rocks, known by the names of granite, greenstone, porphyry, &c., that we infer that they also have had an igneous origin, though not always under the same conditions as those observable in a modern volcano. When, for instance, a mass of granite, *a*, (Fig. 18,) sends out veins, *c c*, into a deci-

Fig. 18.

dedly stratified rock, *b b*, cutting the strata in various directions, the veins even including fragments of the rock, *b b*, we infer that the granite in question was once in a fluid melted state, was protruded through *b b* by forces acting beneath, and that a portion of the melted rock was forced into cracks at *c c*, thus forming the veins in the stratified rock *b b*, the beds of which were also upheaved at the same time. The inferences would be the same whether the protruded rock be granite, greenstone, porphyry, basalt, or others.

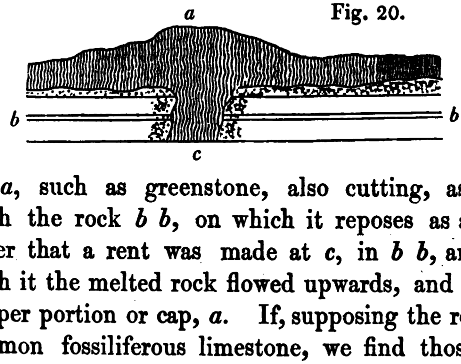
When, as in the annexed view (Fig. 19), a long

narrow mass of rock divides another, in the manner *a* does *c*, and this narrow mass of rock is composed of substances similar to those which constitute greenstone,

porphyry, or the like, we infer that the beds of the rock *c* were once continuous, that they have been subsequently broken, and that into the fractures liquid melted rock arose, filling the cavity formed by the crack. To these intruded masses of rock, consolidated as we now find them, the name of *dyke* is given, and they are known as greenstone, porphyry, basaltic, or other dykes, according to the kind of rock of which they are composed. Even when these masses of intruded rock do not rise to the surface of the land, and are only known to exist by natural or artificial sections, as at *b*, Fig. 19, they are still termed dykes.

We have sometimes good evidence to show that certain igneous rocks have, after traversing pre-existing beds, spread like a sheet over them, leaving masses, sometimes nearly tabular, at others more domed-shaped, above the pre-existing beds. When, as in the annexed section (Fig. 20), we find a superior mass of any given

Fig. 20.

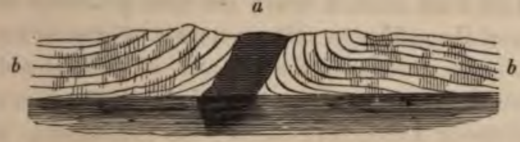


rock, *a*, such as greenstone, also cutting, as at *c*, through the rock *b b*, on which it reposes as a mass, we infer that a rent was made at *c*, in *b b*, and that through it the melted rock flowed upwards, and formed the upper portion or cap, *a*. If, supposing the rock *b b* a common fossiliferous limestone, we find those portions which are in contact with or near the greenstone to be crystalline, or *b b* being sandstone or shale greatly indurated, with even perhaps a tendency to

new arrangements in their component particles, we further infer that such alteration has been caused by the presence of the greenstone when liquid or intensely heated. Deposits which have suffered this change, — more particularly when such effects are observable on the large scale, and the distance from the once heated mass is measured by hundreds of feet and not by inches, —are termed *altered rocks.*

While the melted rock seems in some instances merely to have risen quietly in a crack or fissure, like any other liquid, to a level at which it can be supported by any proper force acting upon it; at others, as in Fig. 21, we find the two rocks so situated relatively to each other, that we can scarcely refuse to consider that the rise of the igneous rock

Fig. 21.



has been accompanied by force. If *a* (Fig. 21) be the intruded igneous rock, and *b b* a stratified deposit, then the beds near *a* being turned up on both sides of the dyke, we should infer that the substance of which *a* is composed had been thrown up with sufficient force to turn up the edges of the stratified rock, *b b*, on either side. It should however be observed, that the upturned character of beds on either side of dykes is more rare than a mere division of the stratified or other rock, without any mark of the violent intrusion of the matter of the dyke.

In some countries very considerable geological effects have been caused by the intrusion of igneous rocks among others of all geological ages, from the lowest known stratified rock to modern deposits inclusive. Sometimes they seem to have been thrown up in the manner of modern volcanos, accompanied by eruptions of ashes and cinders, either into the atmosphere, or some other relatively small superincumbent pressure; at others they appear to have been protruded, either in greater masses, or beneath great superincumbent pressure, producing a variety of effects which it would occupy too much space in this brief sketch to enumerate.

It was once supposed that granite was the fundamental rock upon which all others rested. Without entering into the theory which supposes the granitic to be that form of rock which was first produced if the mass of the earth were once in a state of igneous fusion, it may be considered that granite is more abundant, taken in the mass, among the inferior stratified or non-fossiliferous rocks, than among the fossiliferous class, particularly the more modern deposits of that class. We are not, however, to restrict granite to the lower fossiliferous rocks; on the contrary, we are not yet prepared to say how high up among that series it may be discovered, since it has been detected above the chalk at Weinböhla, and consequently it must have been ejected from beneath, in that situation, during the supracretaceous or tertiary epoch.

The mass of the igneous rocks appears to be composed, in variable proportions, of the silicates of alumina, magnesia, lime, potash and soda, with the occa-

sional and subordinate presence of a few other substances; those rocks being the most fusible in which silicate of lime is somewhat abundant, while the most refractory seem those in which silicate of magnesia prevails. Those in which the minerals named hornblende or augite (the latter probably only a modification of the former) abound, such as greenstones, basalts, and many lavas, are on that account more fusible than those in which mica prevails, such as many micaceous granites. Most granites are however refractory, particularly when quartz is abundant in them. Serpentine also is of difficult fusion; but those rocks in which the mineral named felspar prevails are not, in general, very refractory.

It has been considered that silica is more abundant, viewed in the mass, among the older than among the more modern igneous rocks, while lime (as a silicate) more abounds in the latter. Many of these rocks may never have been in a solid state before they were ejected upon the solid surface of the earth, while others may readily have been produced by the fusion of pre-existing solid rock, and then driven to the surface, in both cases, by sufficient forces acting beneath.

PART II.

As we should, when searching for the causes of any given effects, proceed, if possible, from the known to the unknown, it behoves us carefully to observe the effects of those causes which daily produce geological changes on the surface of the earth, and then, weighing all the circumstances under which the various rocks are presented to our attention, honestly to seek, without bias, to what extent they can explain the production of the different mineral masses which compose the exposed solid surface of the globe. If, after careful investigation, we find that the effects of those causes which are known now to act on and modify the world's surface prove insufficient, or only partially account for, all the phenomena observed, we should endeavour to ascertain the extent to which they are insufficient, and then proceed to inquire how far the supposed greater intensity of similar causes may carry us. Should we still find many phenomena not satisfactorily explained, we must necessarily have recourse to various hypotheses founded on the known laws of nature, waiting until the progress of knowledge generally shall enable us to frame a theory in which the various parts shall be in harmony with each other, and with the whole taken collectively.

I. *Decomposition of rocks.*—There is a tendency in all rocks to decompose by the action of the atmosphere upon them, and to be afterwards carried by lines of

moving water to lower levels than they occupied prior to decomposition, often into the sea, or other bodies of water, where they may be distributed in such a manner as to produce new accumulations of mineral matter, or new rocks as they are termed, in which the remains of existing animal or vegetable life may or may not be entombed, according to circumstances.

a. To appreciate the action of the atmosphere on given rocks, the observer should direct his attention to the amount of yearly or other change caused by it on masses of stone used for buildings, and which are supposed to have been taken from those situations in quarries where such masses have, to a great extent, been secured from atmospheric influence; carefully investigating whether the observed changes may have been caused by the chemical or mechanical action of the atmosphere, and of the substances accidentally contained in it;—that is, he should observe whether any of the component parts of the stone have united chemically with those of the air or the substances contained in it, or whether the external parts have been removed by the friction of water, by the freezing of water in the interstices of the stone, forcing the component particles asunder, or the like. Care should be taken to note the structure of the stone, ascertaining whether it be homogeneous, like compact limestone or marble, or composed of substances which, when exposed to the same causes of decomposition, resist them unequally, such as granite, conglomerates, and many sandstones.

Due attention should be paid to the variations of climate, noting carefully the aspect of the buildings, and if the same materials are differently decomposed in dif-

ferent aspects, endeavouring to show the reasons of such difference, such as the prevalence of driving rains, or of furious winds, more from one quarter than another. An antiquary, if he be a chemist, or call in the aid of one, may in this manner afford valuable geological information, without neglecting his more peculiar studies.

b. To estimate what have been the effects of decomposition in surface rocks between the soil, as it is commonly termed, and the more solid parts of such rocks, the observer will have more difficulty; since he cannot know the amount of time during which they have been exposed to atmospheric influences; neither can he judge with precision as to the quantity of decomposed rock which may have been removed, nor of the variable character of the vegetation above, by which the decomposition has, according to circumstances, been more or less modified. Much may, however, be accomplished by careful observation.

Although on high mountains, where masses of rock are frequently exposed to the free action of the atmosphere, they are often greatly decomposed, we cannot estimate the depth to which a given rock has been *weathered*, as it is termed, so well as on lower grounds; for, on exposed mountains, the form of the surface is generally such that the decomposed parts are readily removed by the action of moving water to lower levels. We might indeed roughly estimate the amount of surface loss sustained by rocks in these situations, by means of the pinnacles and bosses of harder matter which still retain their places, if we could form anything like a just conception of the figure of the moun-

tains after they first occupied their present positions, and before the atmosphere acted upon them. Unfortunately, the stratification of mountain ranges is generally such that the rocks of which they are composed bear evidence of having been greatly fractured when forced into their present positions, and therefore the mountains, for aught we know to the contrary, may even have been more rugged and broken than we now find them.

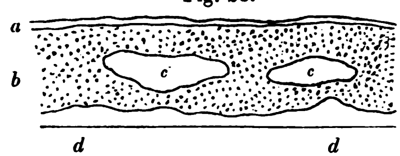
In the lower lands, for instance on the top of broad-backed hills, where there would be a difficulty of removal by moving water, and where it has been carefully ascertained that transported substances have not been carried, we seem to arrive at more satisfactory conclusions. The observer should search for pits on central portions of the broadest part of such hills, and in them he will often detect good examples of decomposition. Perhaps he may find granite decomposed in

Fig. 22.

the manner represented in the annexed section (Fig. 22), in which *a* is the vegetable soil, as it is commonly called, *b* decomposed granite, and *c* granite in its solid form. In such a section as the above, he must be careful to ascertain that the particles of granite at *b* are exactly of the same kind as those at *c*, and that there can be no suspicion of their having been carried into their present position by moving water. Sometimes

he may find the granite decomposed so as to leave large rounded masses of solid granite surrounded by loose decomposed portions. The annexed illustration of this fact (Fig. 23) is taken from part of the road between Okehampton and Moreton Hampstead, in Devonshire;—*a* represents the vegetable soil, *b* decomposed granite, *c c* solid rounded masses of undecomposed granite included in the decomposed part, and *d d* solid granite. In such a section as this the observer should use great

Fig. 23.

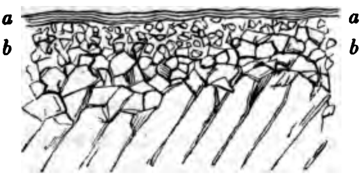


care, so that he may be certain that *c c* are not transported boulders of granite, included in smaller granitic gravel, *b*. Fortunately, in this case, he would be greatly assisted by the presence of large crystals of felspar disseminated through all parts of the rock, both decomposed and undecomposed, and which are beautifully preserved in their relative positions in the former. In the decomposed granite above noticed, the effect produced has been chiefly chemical, a change having been effected in the felspar through atmospheric agency.

Among a variety of hard rocks, the component parts of which do not readily combine with any portion of the air or of the water contained in it, and which are too compact to allow of any considerable absorption of water between their particles, considerable decomposition may yet be produced by the tendency of such

rocks to split into fragments when exposed to the influence of the atmosphere. The observer may often trace the breaking up of a compact limestone or hard sandstone in the manner represented in the annexed section (Fig. 24), in which *a* represents the vegetable

Fig. 24.



soil, *c c* a hard sandstone rock, such as some varieties of grauwacke, and *b b* fragments of the same rock, largest towards *c c*, and evidently constituting portions of the subjacent strata, while the upper fragments are smaller and more confusedly mixed, though still angular.

Probably much valuable information might be eventually obtained, if, when deep excavations are made for roads or other purposes, marks of a given depth and form were cut on the exposed surfaces, with the date attached; notes being made of the fresh condition of the rock when the mark was cut, and of other obvious circumstances, and the notes placed in some common place of security. Care should of course be taken to cut such marks only on such parts of rocks as were not previously exposed to the direct action of the atmosphere, and therefore as far beneath the decidedly *weathered* part as may be convenient, and at the same time secure from other injuries than those of atmospheric agents.

c. The observer must be careful, in his estimate of the amount of decomposition which rocks may sustain from the action of the atmosphere, duly to consider the power of vegetation to prevent, assist, or otherwise modify it, according to circumstances. Vegetation may prevent decomposition, by presenting a certain barrier to the effects of sudden frosts and thaws; assist the mechanical action of heavy rains by keeping the higher parts of rocks more permanently wet than they would otherwise be; or greatly modify it, by the various effects produced according to the kind of plants which may cover the land at given times: for a portion of country covered by forest-trees would be differently circumstanced, as regards the probable decomposition of the rocks of which it is formed, than when the same portion was either broken up for tillage or covered by pastures.

II. *Removal of parts of pre-existing rocks by moving water.*—The decomposed parts of rocks above noticed are necessarily of different sizes, according to the kind of solid rock whence they have been derived, and the circumstances to which their present condition is due. The angular fragments of hard limestone or sandstone, such as are sketched in Fig. 24, would offer greater resistance to any given force of moving water than a fine-grained decomposed sandstone: that is, supposing the same heavy storm of rain to fall equally on both, the loose sand of the decomposed sandstone might be washed away, while the large angular fragments of limestone might remain firm: or, supposing the two different kinds of decomposed rock to be equally exposed to the force of the same rivulet or

river, the one might be carried down the stream, while the other remained in its place.

a. When an observer is desirous of estimating the power of any particular stream or river to carry forward the detritus of pre-existing rocks, formed either by decomposition or by the abrasion of moving water, to be noticed hereafter, he must be careful to take several circumstances into consideration.

1st. The various slopes of the channel should engage his attention; for moving water carries detritus forward according to its velocity, and the latter neces-

Fig. 25.

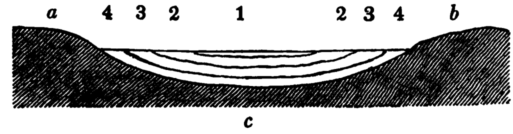
sarily increases with the amount of the slope: that is, if *a b* (Fig. 25) represent the exaggerated slope of a river in one place, and *b c* the slope of the same river in another, and the amount of water be neither increased nor diminished by tributary streams or diverging branches, the river will run much quicker at *a b* than it will at *c b*, and consequently smaller pebbles or finer sand can remain at the bottom of the latter than the former, because the force of the water would wash away much larger pebbles or sand at *a b* than it can at *c b*.

2ndly. The shape as well as the size of the detritus should be taken into account; for two fragments of the same rock, though exactly of the same size, or volume,

as it is termed, may be carried forward by different forces of moving water, if their shapes be different. A common angular fragment of a given rock, for instance, would not be moved at the bottom of a river, when the force of the water was only sufficient to roll on a piece of the same rock of a globular shape, though the two pieces should be of exactly the same size or volume.

3rdly. The relative weights, or specific gravities, of the different kinds of pebbles or fragments of rock should be duly considered; for the force of a river only sufficient to move one kind of pebble or fragment, would be unable to move others of greater weight or specific gravity, though their shape and size were the same. The stream of a river which could only move a ball of marble three inches in diameter, could not carry onwards an iron cannon-ball of the same size, supposing both placed under exactly the same circumstances.

If we knew the velocity of water required to move fragments of given size, shape, and weight, the observer would obviously only have to ascertain the velocity of any river he may have under examination, and he would at once obtain the kind of detritus which it could carry onwards. On this head, unfortunately, we possess little information which can be deemed satisfactory, and therefore direct experiments should be made to clear up the subject. We know, that if *a c b* (Fig. 26) represent the section of a river-course, the



greatest velocity will be at 1, and that it will decrease towards the sides and bottom, as may be represented by the layers of water, *2*, *2*; *3*, *3*; and *4*, *4*; but we do not know the law of this decrease, nor the amount of friction that we ought to have at the bottom and sides, when we have a known velocity of current in the middle (1), and when the depth of water, distance from the sides, and shape of the river-bed are also correctly ascertained. We should anticipate in such a section as that above (Fig. 26), that the friction of the same layer of water, next to the sides and bottom, would not be equal at the banks *a b*, and at the bottom *c*, since the weight of water would be greater at the latter than at the former.

b. The checks which a river may suffer in its course should be duly noted, such as lakes, patches of level land, and the like. Without this precaution it might be, and indeed has been, inferred, that all the pebbles found far down the course of all rivers have been swept onwards by the existing rivers. In some cases this may be true, but in many it is not so. Frequently, when a river takes its rise in high mountains, its course onwards is, though often rapid, interrupted by tracts of level country, or even lakes, where the larger detritus is arrested; and yet pebbles derived from the rocks of the high mountains are found abundantly in the river-bed farther down than these obstacles, such pebbles having been brought down from the higher levels by pre-existing moving water. Thus Alpine pebbles in some of the rivers of Northern Italy could not have been carried into the plains of Lombardy by existing rivers, since the Lago Maggiore, the Lago di Como, and

others, necessarily stop the progress of the pebbles borne from the high Alps by the torrents which feed the lakes.

c. The proper time of estimating the transporting power of a river is during heavy floods, when fragments of rocks can be moved which would remain firm under ordinary circumstances. The observer should endeavour to separate the complicated effects of a flood in a cultivated country from each other, carefully weighing how much is due to the increased velocity of the river; to bodies of water ponded back by obstacles which give way before the pressure exerted upon them; to the transporting powers of sluices of water thus suddenly set in action; and to various other obvious circumstances:—in fact, endeavouring to ascertain what is really accomplished by the velocity of the water, by its weight and volume, or by the united action of its weight, velocity, and volume. He will thus avoid massing all the effects together, and by so doing attribute to one power that which is really due to another.

d. The transporting power of a current or stream of tide passing along a coast is, to a certain extent, the same as that of a broad river on the line of one of its banks. If, in imagination, we withdraw the other bank and substitute the open sea, moving in the direction of the river, we have a stream of tide or a current acting on a coast, and, of course, we have the same laws in force. The friction of the water on the land would retard its progress, and the power of the stream to remove loose matter would depend upon its velocity. Although the projecting headlands or capes would be most acted on, in the same manner as the obstacles to a

river's course, the action of a given velocity of water on a hundred miles of coast would be greatly less than on the bank of a river also one hundred miles long, all other circumstances being equal: for in a river, the stream of water, when thrown off by one bank, is again thrown on it by the other; whereas, on an open sea-coast, it rarely happens that any obstacle throws a stream of tide back again, when it is fairly driven off from the coast, by a cape or headland. It therefore follows that there would be less transporting action, viewed strictly with regard to equal velocity of water alone, on a line of sea-coast than on the bank of a river, all other circumstances being equal.

The proper time to study the effects of a current or stream of tide acting on a coast, is when the sea is perfectly calm,—that is, unruffled by waves. The observer should be careful to attend to this, as from want of due caution, the complicated action of the sea and atmosphere on coasts has often been attributed to the action of one cause only out of several causes. Streams of tide or currents undoubtedly run stronger when forced forward by strong winds, and due allowance should be made for the increased velocity in such cases; still, when we observe a coast at such times, we must carefully separate the action of the waves from that of the mere friction of the moving body of water.

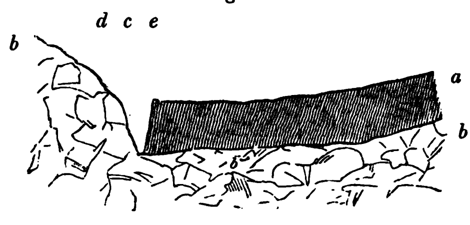
III. *Abrasion of rocks by moving water.*—It will be evident to those who observe a body of clear water driven against some of the softer rocks, that water has the power, when its volume and velocity are sufficient, to abrade rocks. This power is greatly increased when bodies of moving water, such as rivers, are charged with

detritus, since the friction is then greater. The observer should direct his attention to the various circumstances by which abrasion of this kind is effected.

a. If the moving water be a river, the amount of decomposition which a rock may have suffered, before acted on by the river, should be carefully estimated, so that the power of the river to abrade a given rock may not be over-estimated. As it is found that the decomposition of many rocks is greatly assisted by being kept alternately wet and dry, the observer should see whether the water of the river rises and falls in a manner sufficient to have an appreciable influence on the rocks washed by it.

b. In situations where we have reason to suppose that deep cuts or ravines have been formed by existing rivers, it is necessary to weigh well all the circumstances which may have attended such instances of abrasion. If a barrier, such as a lava-current, be suddenly thrown across a valley, the waters behind are necessarily sustained to the height of the lowest part of the obstacle thus opposed to their further progress down the valley. Now, when a section such as that annexed (Fig. 27) is presented to our attention, where

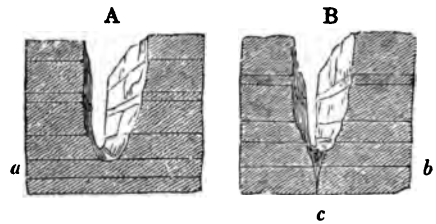
Fig. 27.



a lava-current, *a*, has flowed into a pre-existing valley of granite, *b b b*, and we find a ravine, *c*, through which a river flows, we must not too hastily conclude that the whole depth of the ravine has been produced by the erosive action of the river, since it may easily have happened that the lava-current, *a*, never completely filled up the valley, but that a space was left between the high part, *e*, of the lava, *a*, and the bank of granite, *d*. We might, *à priori*, infer that there would be an open space at *c*, resulting from the contraction of the mass of the lava-current, *a*, by cooling. Neither should we conclude, supposing the lava did rise to a proper height against the granite bank, *d*, that the same body of water would in the same time cut through the lava-current itself to the same depth, since, in the case of the section before us, the river in the ravine, *c*, would not only act with considerable advantage on the line of separation between the two rocks, but in all probability the outer side of the bank of granite, *d*, would have suffered by weathering, or the action of the atmosphere upon it, before the lava-current traversed the valley. When, therefore, the abrading power of the river was brought to act violently upon it, as would be the case under the circumstances above noticed, its destruction would not afford a satisfactory measure of the action of the same force of water on the solid granite during the same time.

c. Before the observer concludes that any ravine he may find has actually been cut by a river now flowing through it, he must be certain that the ravine is not the result of a great crack in the rocks which constitute its walls. When, therefore, he discovers a ravine which

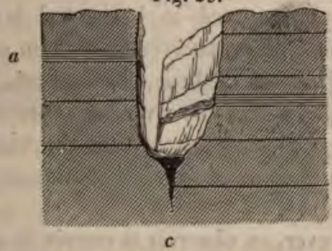
Fig. 28.



appears to have been cut by the abrading power of the river in it, he must carefully look for good evidence that it is not a crack, for such is not unfrequently the case. Let A and B (Fig. 28) represent two sectional views of two ravines, and let us suppose an observer placed in either endeavouring to ascertain their origin; he might conclude, from their general appearance alone, either that they were cut by the rivers in them, or were cracks, as best accorded with his preconceived opinions. To clear up this point, he must see if the two sides of the ravine are in any manner connected by a ridge or ledge of rocks. If he find one, he should in the next place ascertain whether any bed of rock, such as *a*, goes clearly across the river and is unbroken; because, if unbroken, he has direct evidence that the ravine is not due to a crack, but is an excavation in the body of the rock, as shown at A. If, on the contrary, he find no marked bed of rock extending continuously across the river, the evidence is uncertain; for the blocks, pebbles, or sand, as the case may be, in the river-course, may either cover such continuous beds, or the head of a crack such as that represented at *c* in B.

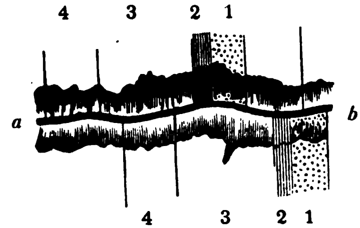
In the above sections (Fig. 28) we have made the rocks to correspond on either side of the valley, for the sake of more easy illustration. Should, however, the observer find the beds of rock on either side of the ravine so situated as to relative levels that they would not join, though horizontal, if prolonged towards each other; that is, if he discover, as in the annexed section (Fig. 29), that a horizontal and marked bed, *a*, was

Fig. 29.



higher on one side of the ravine than on the other,—he would at once perceive that the river has worked upon a crack, *c*, and that probably there has been compound action productive of the ravine — first, a crack in the body of the rock, and secondly, abrasion by running water along the line of the crack or fissure. Should he also find, supposing the beds of rock vertical, that they would not respectively meet if prolonged in the lines of the beds towards each other, he would infer that the body of rock had been dislocated, and that the river, if there be one, ran upon the line of dislocation. Let the annexed figure (Fig. 30) represent a map-sketch of a ravine, *a b*, through which a river flows, the various beds of rock on either side being vertical,

Fig. 30.



instead of being arranged in horizontal layers, as in Fig. 29. Should the observer find upon examination that a marked series of beds, 1, 2, 3, 4, would not meet if prolonged across the river, as represented above (Fig. 30), he will then know that the whole body of rock has been dislocated, and that the river runs in the line of fracture.

When, however, an observer is certain that any ravine is the higher part of a greatcrack or break in the continuity of the rocks on either side, he will still have to estimate the probable abrading effects of the river flowing upon such a crack or break, weighing well the general condition of the channel, the hardness of the rocks composing the walls of the ravine, and of the pebbles and pieces of rock forced down by the river, particularly during floods.

d. When there is reason to suppose that a lake has once existed in some principal line of valley, either from there having been a rise of the general bottom at one particular place, or that a lava-current has run across the valley, damming up the descending waters, and that the waters of the lake have been drained by gradually working down the barrier,—the observer must

study the probable height of the dam before it was cut through, in order to obtain an estimate of the body of water kept back, the amount of fall to the lower levels, the velocity of the descending waters, and the force of the abrading power. Let the annexed diagram (Fig. 31)

Fig. 31.

represent the longitudinal section of a lake, *a*, kept back in some principal valley by a lava-current, *b*, which has crossed it; then the height of *b* above *c* (the channel of the river below the obstacle *b*, and forming part of the former continuous channel *c d*,) would afford an estimate of the velocity with which the surplus waters of the lake, *a*, would rush towards *c*, and consequently of its abrading powers. This velocity, and consequently the abrading power, would decrease as *b* was gradually cut through, and the amount of fall became less.

e. The observer should not neglect the abrasion by minor streams and heavy falls of rain; for though it may not at first sight appear very considerable, yet, collectively viewed, small streams of water carry forward a great body of the smaller detritus to lower levels, where it is either accumulated in favourable situations, or transported onwards by the principal rivers, which throw much of it into the distributive power of the

sea. In the tropics, the observer will find the abrading power of a few hours' rain very striking, particularly in those favourable situations where there is no protection from the dense vegetation so common in such countries.

f. There has been scarcely any power more overrated by geologists, since attention has been paid to facts, than that of marine currents and streams of tide to abrade the coasts which they wash, and to excavate valleys in the bottoms beneath them. This seems mainly to have arisen from a want of correct observation, and sometimes from the absence of any definite idea of the power theoretically called into action. Hence have arisen the almost inconceivable errors respecting the geological effects produced by such agents. The attention of the observer has been called above to the transporting power of currents and streams of tide. To estimate the abrading effects of these powers, he should well weigh the velocity of the waters thus thrown into motion, the depth to which such velocity extends, and the retardation of the moving water as it approaches the coast or bottom, where, in point of fact, its abrading power begins. Duly to estimate the amount of abrading action, the observations should be made at the seasons and times when the currents or tides are in full force, and yet when the sea is perfectly calm. They should also be made at the junction of the water with the land, where alone any abrasion can take place. It may be almost needless to remark, that the proper time to estimate the abrading power of a tidal stream is during *high springs*, as they are technically termed, when the streams of tide run strongest.

IV. *Abrasion of coasts by waves.*—We may here

notice this power, which is the greatest land-abrading force with which we are acquainted, particularly when its effects are collectively considered.

a. Properly to estimate the effects of this power, the observer should be present on some exposed coast, such as that of the western part of Ireland, the Land's End, Cornwall, or among the Western Islands of Scotland, during a heavy gale from the westward, and mark the crash of a heavy Atlantic wave when it strikes the coast. The blow is sometimes so heavy that the rock will seem to tremble beneath his feet. He will generally find in such situations, that though the rocks are scooped and caverned into a thousand fantastic shapes, they are still hard rocks ; for no others could continue long to resist the almost incessant action of such an abrading force. Having witnessed such a scene, he will be better able to appreciate the effects, even though the waves be far inferior in size, upon the softer rocks of other coasts.

b. The observer should carefully remark the direction of the prevalent winds, and the proportion of those which send the greatest waves, or seas as they are termed, on shore, in order that he may duly appreciate the loss of coast sustained in those directions where the force of the breakers is greatest and most incessant. Thus, on a coast on which western winds prevail, and there is a sufficient extent of open sea before it, we should expect to discover the greatest amount of destruction produced on points exposed to the westward, while rocks of equal hardness might be less abraded in places open to the eastward.

c. The attention of the observer should be directed

to the rise and fall of tide on tidal coasts, when estimating the abrading power of waves on such coasts; since a greater surface of rock, all other things being equal, is exposed where the rise and fall are great, than where they are small. Moreover, the rock is exposed to greater decomposition from being alternately wet and dry, in proportion to the surface so wetted and dried. It must not, however, be forgotten that coasts, where breakers reach the cliffs at high water, are frequently protected by beaches at low water; and that therefore they are removed from the abrading power of the waves during all the time that they break on the protecting beaches—a time which varies with the varying state of the tides and the state of the weather generally.

d. An observer will scarcely have long directed his attention to the abrading power of waves breaking on coasts, before he will discover many circumstances which modify the effects that would be otherwise produced. He will see that the abrasion of coasts is often greatly assisted by land-springs, as they are termed, that, as it were, shove the cliff into the power of the breakers by moistening a body of rock, which thus loses its cohesive powers and is launched in the direction of least resistance, or seaward. Other encroachments are made by the fall of masses of cliff undermined by the waves, the cohesive power of the rock not being equal to its weight or the action of gravity downwards. If, as in the annexed sketch (Fig. 32), a rock be even sufficiently cohesive in the mass as to admit of the considerable excavation there represented without falling, a time must come, if the breakers con-

tinue to work on in the same direction, when the weight of the superincumbent mass would be such that it must fall.

Fig. 32.

When, however, a great mass of cliff does fall, in the manner noticed above, the observer should direct his attention to its conservative influence. To appreciate this, he will consider the hardness of the rock, the position into which it has fallen, and its new power of

Fig. 33.

breaking the waves farther from the coast. If the mass of fallen rock be stratified, much will depend upon the face presented to the breakers; for if it fall so that the plane of the beds remains sloping seaward, as in Fig. 33, it will act as a well-contrived wall erected to defend the cliff: but if the beds should be exposed vertically

Fig. 34.

after the fall, as in Fig. 34, the future destruction of the mass would be far more rapid, and its conservative influence consequently less.

While on this subject, it may be noticed that incrustations by marine animals and seaweed tend greatly to protect the bases of cliffs on tidal coasts; and the observer should particularly direct his attention to the conservative influence of the *Balanus* in many situations.

e. The observer will sometimes find, when a soft rock forms the base of a cliff, and a hard rock the upper part of it, that the fall of masses of the upper part, in consequence of being undermined, will protect the

lower part from further destruction for a time depending on various circumstances. Let the annexed diagram (Fig. 35) represent the section of a cliff, the

Fig. 35.

upper part of which is composed of a hard rock, *a*, resting upon a softer rock, *b*; then the action of the sea, *d*, upon the cliff would undermine it, and cause the fall of masses of hard rock, *c*, which thus accumulating at its base, would protect it, according to the quantity of rock fallen, the size of the masses, and their hardness. The observer will find that such fallen portions of the harder parts of cliffs, whether they be fragments of harder superincumbent rocks, or indurated concretions of softer beds, greatly modify the abrading power of the breakers on a coast, particularly during the lower states of the tide.

f. The actual power of breakers to triturate fragments of rocks according to their hardness, and consequently the relative powers of given rocks to resist such action, may often be roughly appreciated in beaches collected in favourable situations. Great care should, however, be taken to pay due attention to the circumstances attending the production of the beach, and more particularly to feel assured that pebbles derived from any conglomerates which may exist in the vicinity are not mixed with fragments of the same kind of rocks

detached in the present day from the cliffs on the existing line of coast. The same remark applies to rounded gravels brought down by neighbouring rivers, or washed out of the cliffs.

g. When an observer attempts a general estimate of the abrading power of waves on an extensive line of coast, he will do well to direct his attention, not only to the relative hardness of the rocks composing it, but also to the position of the beds, if the rocks be stratified. He will not fail to perceive how frequently lines of coast, under otherwise equal circumstances, depend on the direction and dip of the strata. Their position with respect to the force of the sea is necessarily important; for if a series of beds such as those in the annexed sketch (Fig. 36) dip seaward, the action of the sea

Fig. 36.

upon them can be but relatively trifling, since the return of one wave down the slope diminishes the force of the next falling on the coast, and what remains of it is gradually expended by running up the slope, in which there is no projecting part to offer resistance to its course. The positions in which the edges of the beds of any given rock are exposed to the action of the breakers, are those where the loss by abrasion is

Fig. 37.

greatest. Let us suppose that the annexed sketch (Fig. 37) represents a line of coast exposed to the North and West, and that the abrading power of the waves is equal from both points; then the real effect produced will depend upon the resisting powers of the rocks themselves. If we now suppose the country composed of any given rock, such as grauwacke, and the direction or strike of the beds from E. to W., and their dip about 45° to the N.; then the resisting powers of the rocks will be great on the north coast, since the beds shelve seaward in that direction, while the same rocks will be exposed to much abrasion on the west coast, since the edges of the beds are exposed in that direction, and numerous indentations will be the result.

Even in cases where beds of rocks on coasts shelve seaward, the abrading power of the breakers is still frequently apparent. The sea often works upon the land by means of the cleavage fissures of the rocks themselves, or on the fractures caused by faults: nevertheless, the protecting power of strata which do thus shelve is always sufficiently observable.

h. The observer would always do well to inquire from aged fishermen and others, on coasts where he suspects the loss of land has been great within the

memory of man, how much has gone within their recollection; not contenting himself with loose generalities, but compelling specific answers as to the actual quantity lost, with their recollection of what was done with such portions before they were removed by the action of the sea. The author has sometimes been told of vast losses in this manner, which have subsequently turned out to be relatively trifling; while, on the other hand, they have sometimes been underrated. Little dependance can be placed on old maps of coasts, which are for the most part exceedingly inaccurate; indeed, there would be no difficulty in producing those which would, when compared with a modern good survey, show an increase of half or three quarters of a mile on a coast where, in point of fact, there had been considerable loss.

V. *Mechanical deposit of detritus in river-courses and on plains.*—From the various causes above noticed, a large collective amount of detritus, or variously sized portions of pre-existing rocks detached from them by decomposition or abrasion, is mechanically suspended in moving waters, from which it is precipitated under favourable circumstances.

a. Fully to appreciate the distance to which the various kinds of detritus may be carried by moving water, until they be deposited, an observer should direct his attention to the quantity and kind which can merely be pushed forwards by a given velocity of such water, acting on the bottom or sides over or against which it may flow, and to the quantity and kind the same velocity may keep mechanically suspended at the same time. In the former case, the friction of the

water on the bottom or sides is the cause of the forward motion of such detritus; while, in the latter, the particles of detritus are, as it were, shaken up among the particles of water by sufficient velocity and agitation, upon the same principle that fine silty matter, placed in a bowl of water, is shaken up into the water by agitation. As the silty matter remains mechanically suspended in the water of the bowl as long as the necessary agitation continues, so does rock detritus continue mechanically suspended in larger bodies of water until the agitation be insufficient to keep it so suspended, when a settlement takes place.

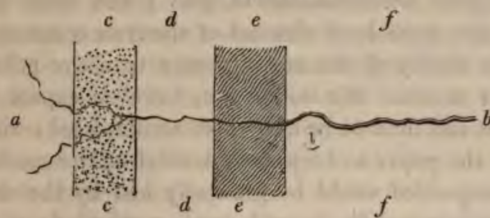
b. The observer will not fail to remark, that in torrents rendered turbid by the wash of detritus into them, from heavy falls of rain or other causes, the water is in a constant state of agitation, and that silt and sand are only deposited in those places where this agitation is insufficient to keep them mechanically suspended. Moreover, he will see that upon the amount of velocity and agitation depends the size of the detritus which can be carried forwards. Some of this detritus is mechanically suspended in the torrent, while other portions, necessarily the largest, are pushed forwards by its friction against the bottom and sides. Two causes therefore are in operation at the same time, both tending to carry portions of pre-existing rocks to lower levels.

c. When an observer detects detritus of a particular kind disseminated through moving water, he must not too hastily conclude that the velocity with which the water is then flowing is sufficient to keep such detritus permanently suspended; that is, that such detritus

would continue to be mechanically suspended so long as such velocity remained the same. Detritus disseminated in still water experiences a mechanical difficulty in descending to the bottom in proportion to its fineness. The same law holds good in moving water; though probably such difficulty is increased in proportion as the velocity of the suspending water increases, until finally the velocity be sufficient to keep it mechanically suspended. There will, however, evidently be a point where the power of mechanical suspension from agitation ceases, and the power of settlement begins, the latter increasing as the moving water is gradually brought to rest.

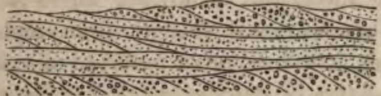
d. Attention should be directed to the appearances of deposits caused by the various modes in which they may be effected. A deposit resulting from the pushing process, itself arising from the friction of moving water on the bottom or sides over or against which it may pass, would necessarily present a different appearance from one gradually formed by the settlement of mud, silt, or sand in still water. The pushing process would continue as long as the pushing power of the water continued,—or, in other words, as long as the moving water possessed sufficient velocity and weight. An observer may estimate the power of a river to push detritus along its course by examining the pebbles and sands in its bed, due regard being paid to various circumstances previously noticed, and a knowledge having been obtained of the various rocks existing in the course of the river. Let the annexed sketch (Fig. 38) represent the course of a river, *a b*, through a country composed of marked rocks, *c c*, *d d*, *e e*, into a low country *f f*, where its movement becomes sluggish; and

Fig. 38.



let the fall of the river-bed from *a* to the low country be sufficient to produce a stream capable of pushing forwards pebbles of the size of an egg, where its full force can be directed against them. If the river be capable of forcing such pebbles onwards, it follows that, all other circumstances being equal, it can drive forwards those of less size, and that finally there will be a size which the velocity of the river can keep mechanically suspended in its waters. There will necessarily be a deposit of the detritus pushed forward wherever sufficient obstacles present themselves; and as the river would vary in its power to do so according to the quantity of water in it, such deposits would possess an irregular character somewhat resembling the annexed section (Fig. 39), depending on small shifts in the directions and force of the propelling current.

Fig. 39.



In the sketch (Fig. 38) we have supposed the river capable of propelling pebbles to the commencement of

the low ground, *f f*; therefore the observer would look for irregular accumulations of gravel and sand at *l*, where the more level channel of the river commences, and the ability of the moving water to shove pebbles onwards ceases. He would not, however, expect the finer silt and mud to be also there accumulated; since, though the power to keep such detrital matter mechanically suspended would be gradually lost by the river, the time required for its settlement, particularly of the finer parts, might be such that the whole body of water may continue to move down through the low-land in a turbid and discoloured condition, slowly parting with the detrital matter disseminated through it; the agitation of the moving water being frequently such as to keep the mud and silt suspended until the whole be stopped by a body of still water, such as a lake or the sea.

e. A deposit of transported detritus could not be otherwise than produced along the line of a river under the circumstances above noticed; and hence we should expect, unless such deposits were cut up by floods and thus carried still farther forwards, that the bed of the river would be raised. To this circumstance the attention of an observer should be directed. For the most part, the power of a stream to keep its channel clean, and even to work it deeper, after the principal hollows are filled up, is obvious where it runs with rapidity; but where it changes from rapid to slow and sluggish, it will be often found to raise its bed by the accumulation of detritus which has been gradually *shoved* from the higher levels downwards. In broad plains much alluvial matter seems to have been collected

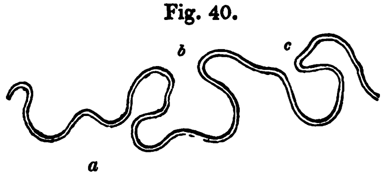
by the raising of channels, and the tendency of the rivers to quit such raised beds and flow in lower levels, which are in their turn also raised, so that eventually the whole plain acquires a certain additional increase in height. It follows, that if, in such rivers as tend to raise their beds, artificial embankments be formed, the rise of bed will be more rapid than where the detritus can, during floods, be forced off on either side upon the lower levels. Now this is found to be matter of fact, and the traveller in many parts of Italy will be more particularly struck with it, because the plains of that country have been long under cultivation, and it has been necessary to protect such lands for an equal length of time from the ravages of the rivers which flow among them. This having been accomplished by continuing to raise the embankments in proportion as the river raised its bed, the road across some of these rivers traverses a corresponding line of elevated ground.

f. It must not be supposed that the sands, clays, and gravels, often termed alluvial, of all great plains, have been produced by the deposition of detritus brought down from higher levels by rivers; because, from the organic remains detected in such sands, clays, and gravel, we have often evidence that some have been produced beneath the waters of a sea, and others apparently in those of lakes. Moreover, fragments of rocks contained in the gravels of level lands are sometimes of kinds and magnitudes which could not have been drifted into their present situations by existing rivers. An observer therefore, before he concludes that the sands, clays, or gravels of any given plain have been accumulated from detritus deposited by existing rivers, should

carefully search for sections of the level land, either along the banks of the river itself, in the gulley water-courses which communicate with it, or in artificial excavations, such as wells and the like. He should in such situations search very carefully for organic remains, because frequently the kind found will afford him valuable information. He should also search among the pebbles of gravel beds, and see whether there are any derived from rocks not comprised within the present drainage of the country, by the existing rivers or their tributaries, to the spot examined. Even when he finds no other pebbles than those of rocks comprised within such drainage, he should carefully consider whether they could, from their magnitude or other circumstances, have been brought down to their present localities by any force of water which could reasonably be attributed to the existing rivers even during extraordinary floods.

g. There are few persons, probably, who have not remarked that rivers are greatly disposed to serpentine in level countries. A small obstacle seems readily to have diverted their courses when they first flowed in such situations. If the velocity of such serpentine

Fig. 40.

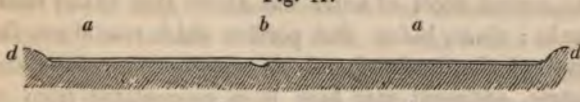


rivers be sufficient to abrade their banks, they will necessarily work most effectually at the bottom of each bend, because there they meet with the greatest obsta-

cles to their onward course. Hence, if two bends are opposite to each other, as those of the river in the annexed sketch (Fig. 40) are at *a*, *b*, and *c*, they will tend to approximate to each other and finally to meet, when the channel of the river will be shortened by the amount of the bend. Changes of bed thus produced are, as is well known, common in the Mississippi, and must of necessity take place in any river where similar circumstances occur. By this process, considerable shifts of the detritus brought down by a river may be effected; and consequently, if there be any resulting deposit over a plain, it will be of an exceedingly irregular character.

h. When an observer sees a tract of level country flooded, or covered by the turbid waters of a river which has overflowed its banks, he should endeavour to appreciate the quantity of solid matter that would be added to the land, if the waters subsided so gradually as to permit the deposition of a large portion of the fine detritus disseminated through them. He may estimate the amount of solid matter thus held in suspension over a given area at any one time, by procuring some of the water in a vessel holding a given quantity,—a cubic foot for instance,—and after allowing the turbid water to clear itself by precipitation, by ascertaining the relative amount of the precipitate; so that by calculating the depth of the water over the flooded area, and the size of the area itself, he would obtain the amount of solid matter which *might* be added to a particular

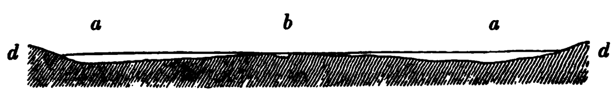
Fig. 41.



piece of lowland country by any one flood. If the annexed section (Fig. 41) represent that of a level plain, *c c*, through which a river, *b*, passes, which has overflowed its banks in consequence of heavy rains, and spread out in the directions *a* and *a*, until it is stopped at the rising lands, *d d*; then, during the subsidence of the river-waters generally, it can scarcely happen but that a considerable portion of the turbid waters would find their way back into the river-course, *b*, and thus, admitting a small general deposit while the whole body of water was kept up, the flat land would not gain the addition of precipitated detritus which might at first sight be supposed.

The case will, however, be different, if, as in the

Fig. 42.



annexed section (Fig. 42), a river, *b*, has raised its bed, so that there are large tracts of country at a lower level on either side of it. If a flood takes place in such a river, spreading over the adjoining country in a sheet of turbid water, *a a*, until stopped by rising lands, *d d*, then *all* the solid matter disseminated in such sheets of turbid water, below the level of the river-banks, would be deposited on the lands which they cover; and there may be an additional quantity obtained, if, when the whole country was flooded, the level of the general sheet of water was above that of the river-banks; since, before that portion which rose above the level of the banks found its way back to the river-course, sediment may have been precipitated from it.

Viewing this difference in the cases noticed, an observer will do well to ascertain whether or not the bed, or rather the banks of a river in a plain, do or do not rise above the level country generally. This is of necessity a delicate operation when plains are extensive; but it should be strictly attended to when we wish to estimate the amount of fine solid matter which may thus be spread over extensive tracts of low lands, such as the plains of India.

i. Before we pass on to another subject, it may be necessary to call the attention of the observer to those accumulations of detritus which are often brought by transverse tributaries into the main rivers of mountainous districts. If the tributary deliver itself with its full force at the same level, or nearly the same level, into the main stream, then there is generally no great accumulation of detritus, except under extraordinary circumstances, such as a heavy fall of rain in the country drained by the tributary, which is not felt higher up the main stream; for then, by the increased transporting power of the tributary, a body of detritus may be driven into the main river which it cannot remove, so that in extreme cases the latter may even be dammed up for a time, and a debacle be the consequence, when the main river overcomes the resistance opposed to it, and drives the loose detritus before it. When, however, as in the annexed sketch (Fig. 43), the tributary comes through a lateral gorge, at a level considerably above the main river, it tends to deposit the detritus it may force forward in the form of a half cone, or one divided perpendicularly to its base. This form it will retain if the main stream be not so close as to work upon its base and carry it away; and in favourable situations, such

Fig. 43.

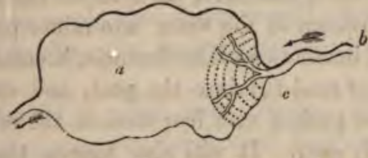
as in some parts of the Alps, cottages and cultivation will be seen in those parts of the mound where the more or less divided streams of the tributary do not rush furiously onwards to the lower levels. An observer will do well to direct his attention to the mode in which angular masses of rock, both great and small, are mixed up, pell mell, with clay, sands, rounded pebbles, fragments of trees, &c. in these accumulations, which are sometimes considerable; since it may assist him when he comes to consider the probable origin of various kinds of conglomerates among the older rocks.

VI. *Deposit of detritus in lakes and seas.*—As the greater number of rocks divided into beds, and hence termed stratified, are supposed to have been formed by the deposition of sediment beneath the waters of lakes and seas, it becomes important carefully to observe the manner in which rock detritus brought by rivers, or derived directly from coasts, is thrown down on the bottoms of the present lakes and seas. In such cases as are concealed from sight, and which unfortunately

are somewhat numerous, the observer should endeavour to approximate as nearly as possible to the truth, by carefully weighing the various circumstances which may produce the deposit of sediment in such situations, due regard being paid to the operation of local modifying causes.

a. An observer may derive much information as to the mode in which detritus is pushed forwards by rivers into bodies of still, or comparatively still, water, by watching sand carried down by a rivulet into a pool of still water, where the sand is no longer forced onwards, and where it consequently accumulates. It is obvious that similar effects may be obtained by casting loose sand into a stream of water, the velocity of which enables it to push such sand forwards to a still pool into which the rivulet delivers itself. It will in either case be found that little heaps of sand are formed where the rivulet enters the pool, and that the accumulated sands tend to arrange themselves so as to constitute little truncated semi-cones, if we may be allowed the expression, on the fan-shaped tops of which the channels, over which the moving water pushes the grains of sand, are continually shifting. If, in the accompanying sketch (Fig. 44),

Fig. 44.

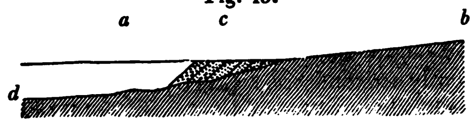


a represent a pool of still water into which a rivulet, *b*, pushes forward sand, then such sand will be found to

accumulate at *c*, falling down into the pool, *a*, in such a manner that a little truncated semi-conical heap of sand is produced, which increases superficially, as is shown by the concentric lines at *c*.

If now the observer direct his attention to the vertical manner in which the grains of sand are accumulated, he will find that they arrange themselves as in the annexed section (Fig. 45), in which *a* represents the

Fig. 45.



surface of the pool, *d* its bottom, *b* the slope of the rivulet pushing forward the grains of sand, and *c* successive coats of sand formed by the grains falling over into still water, such grains supporting each other at angles of 45° or less, according to circumstances, in the same manner as may be seen in any rubbish-heap from the top of which rubbish is continually thrown over. The velocity with which the grains of sand are forced forwards by the rivulet will cause the successive coatings of sand to be inclined at a less angle at first than afterwards; for as the little heap accumulates, and its flat top becomes extended, the force of the stream will, from the division of the water into minor parts and the diminished inclination of the channels, become less where the grains of sand fall into the pool, and consequently they will be pushed with less force to the edge and fall more lightly over. It will also happen that the little stones, which the stream may be able to shove forwards during the production of the first layers of the little

heap, the rivulet may be unable to push over the flat top of the latter after it has become somewhat extended into the pool.

If, when the heap of sand has been accumulated to the extent desired, the water of the rivulet be turned off on one side, and the pool pumped out so that the form of the little heap of accumulated sand remain uninjured, the observer will be enabled to study it. Let him now carefully divide the heap perpendicularly with a sharp spade or other cutting instrument, and he will obtain a section that will enable him to examine the mode in which it has been formed. This, however, he will not in general very clearly see if the sand be of one kind and colour; but if he will throw, as the author of these pages has done, variously coloured sands, and of differently sized grains, into a rivulet which could move them onwards to the experimental pool, care being taken that one colour and kind is fairly washed down before others are thrown in, he will very readily see the inclined positions of the resulting concentric layers. If the experiment be conducted so that the water in the rivulet be increased and diminished at pleasure, thus enabling it to carry forward larger detritus at one time than at another, sometimes even rendering the waters turbid and allowing a sedimentary settlement in the pool, the observer will obtain a great variety of results, the importance of which he will speedily see.

b. The mode in which rock detritus, shoved along the bottoms of rivers by the force of their currents, and subsequently pushed into lakes or seas, is accumulated in such situations, is precisely the same in principle as

the accumulation of sand in the manner above noticed. From the different magnitudes of the objects, the effects are greatly more striking in the one case than in the other, and the modifying causes are more apparent; yet the principle remains the same, and layer beyond layer is added to the larger mass in the same way as they were added to the smaller. The stones or sands, as the case may be, are shoved to the edges of the greater accumulation of loose materials, where, losing the support which they had previously received from the river-channels, they fall over and arrange themselves according to the laws which govern bodies under such circumstances.

c. If an observer direct his attention to the manner in which detritus is protruded into any great lake, such as those of North America, Switzerland, or Northern Italy, it will rarely happen but that he will find considerable variation both in the kind and in the mode of the deposit thus thrust by the different rivers and torrents into the lake. Hitherto we have only considered the friction of rivers on their channels, by which detritus is shoved forward into still water : it is, however, necessary to call the attention of the reader to the detritus which is either held in mechanical suspension by the agitation of the river-water, or which is in the act of falling through it to the bottom when discharged into the lake. Let us suppose that the accompanying sketch (Fig. 46) represents a lake divided into two unequal portions by the approach of the opposite shores to each other in one place, and that an observer is desirous of appreciating the effects produced by the deposition of detritus brought down by the feeding-

Fig. 46.

rivers, *c*, *d*, and *e*. He will in the first place take into account the velocities of the respective rivers, and this he may roughly estimate by the slopes of their respective channels, due attention being paid to the relative quantity of water in each; he will then proceed to consider the relative permanence of given quantities of water in each river. In the case before us, let *c* be the main feeding-river, flowing from a relatively considerable distance, always pouring a considerable body of water into the lake, the surplus waters of which escape by the discharging outlet, *f*; and let *d* and *e* be the channels of two torrents which occasionally descend from mountain heights on either side of the lake with considerable force, while at other times they contain little water.

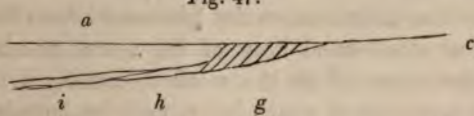
Let us further suppose that the waters of the river *c* are generally turbid, like those of the glacier waters of the Alps, though they vary considerably in quantity according to circumstances, as is usually the case with most rivers; so that *c* has the power of transporting and pushing detritus unequally. It will be clear that the effects produced by the river *c* will be more constant than those caused by the torrents *d* and *e*, though

it may not send so great a quantity of solid matter into the lake in a given time as is done by the torrents *d* and *e*. This will however depend upon a variety of local circumstances. We will suppose, for the sake of illustration, that the collective amount of detritus thrown into the lake (Fig. 46) by the two torrents *d* and *e* is equal to that carried forward by the river *c*.

With these data before us, let us see the manner in which we may estimate the effects produced. If we were examining any given lake at present, one in which the filling process had been going on for a great length of time, we should take the present relative depths into account, particularly if desirous of forming any estimate of the time required to fill up the lake by means of the detritus now borne or thrust into it. To form, however, a clearer idea of the kind and distribution of the deposits that would be produced according to the above-noticed data, we will consider the commencement of the filling process, and, for greater simplicity, suppose the depth of the lake nearly uniform throughout, though of course the primitive form of the lake-basin would influence the products. The river *c* would accumulate the detritus it pushes along its channel by friction, in the form previously noticed, while at the same time it will pour a body of turbid water into the still waters of the lake. The force of the former is checked by the latter, and the turbid water, being heavier than that of *fresh-water* lakes, sinks in clouds towards the bottom, as may be well seen where the Rhone enters the Lake of Geneva, and in various other similar situations. The velocity with which the turbid water enters the lake carries it to various proportionate

distances; but its motion being finally checked, the sediment is deposited. As the detritus would be carried farthest forwards in proportion to its fineness, we should obtain complicated effects, something like those represented in the annexed section (Fig. 47), where *c* being

Fig. 47.



the river, and *a* the surface of the lake, *g* would be the detritus accumulated by the pushing process; *h* and *i*, deposits from the turbid waters checked in their motion by the lake, the sediment being sandy at *h* and muddy at *i*, because the larger suspended detritus would sooner fall from the checked waters than the finer matter. It will be obvious that, after a time, the detritus, merely pushed forward, will accumulate over the sediment thrown down from the turbid water, and that therefore inclined beds of coarse detritus would cover the nearly horizontal accumulations of fine sediment. It would take up too much of our space to enter into a detail of the complicated effects which might be produced; but many can readily be conceived.

To return to the sketch of the lake (Fig. 46). Let us suppose, that from the complicated effects noticed above, the general resulting mass of sediment, deposited or pushed forward by *c*, occupies the dotted area *a*, covering the whole of the small lake and extending a short distance into the larger lake. We have now to consider the effects produced by the torrents, *d* and *e*; and the case may be rendered more illustrative, if we consider that,

from the nature of the rocks traversed by the respective torrents, fragments of hard rock only are shoved forwards by *d*, while much earthy matter and soft rock, easily comminuted by friction, is mixed with the harder fragments thrust into the lake by *e*. If little earthy matter be carried forward by *d*, the accumulation where the torrent enters the lake would form little else than a semi-conical heap of fragments, which would become truncated in the manner formerly noticed, as layer accumulated above layer, and the bottom of the lake would be little covered from this cause beyond the heap of fragments. With the torrent *e* the effects would be somewhat different: we should obtain the heap of fragments as in the other case, but it would be mixed with softer matter, and a quantity of turbid water would be poured into the lake, from whence there would be a sedimentary deposit as in the case of *c*.

Thus we ultimately obtain a heap of hard, and, in all probability, angular, fragments at *d;* a similar heap, though mixed in a more confused manner with softer substances, at *e*, to which is added a mass of sandy and muddy sediment, that we may suppose, for illustration, covers the dotted area *b*; and an accumulation of pushed fragments, in all probability more or less rounded, if much rolled, and of finer sedimentary deposit, at *a*. If we now take into consideration, that the deposits would be greatly modified by variations in the quantity of water in the rivers and torrents at different times, particularly in *c*, we have a very complicated general deposit, which would still undergo modifications as the filling process continued; so that eventually if the lake were filled up, and any great geological change produced various sections

of its solid contents, there would be very little mineralogical resemblances in its different parts. It must not however be forgotten, that the greater the predominance of any one cause, the more would the general resulting effects resemble each other. For instance, the Rhone is the principal filling agent in activity in the Lake of Geneva; and if, in imagination, we contemplate the whole lake filled up, sedimentary matter, derived from the glacier waters of the Rhone, would be the characteristic deposit.

d. The principle on which detritus is pushed by rivers into the sea is the same as that on which it is forced into fresh water; but there are several modifying circumstances which the observer should be careful to take into account when estimating the effects thus produced. The various protrusions of deposited detrital matter known by the general name of *deltas*, such as those of the Nile, Indus, Ganges, &c., consist both of detritus forced forward by the friction of the river-waters on their channels, and of other detritus thrown down from mechanical suspension in the same waters. One main point to be taken into consideration is, that the specific gravity of sea-water is greater than that of fresh water, —that is, it is heavier; and hence it happens that turbid river-water, unless it be considerably charged with mechanically suspended detrital matter, is still lighter than sea-water, and will flow over it to a distance proportionate to the velocity and volume of the river discharging itself into the sea, all other things being equal.

Instead, therefore, of the turbid river-waters falling down in clouds, as happens in the case of turbid rivers

discharging themselves into fresh-water lakes, they would have a tendency to float upon the sea-waters, and to be carried, either by the current produced by the river, or by tides and other causes, to a greater distance than they would be in fresh-water lakes, however large these may be. From this cause, a more general and uniform deposit may be effected beneath the sea than beneath fresh waters, from the same quantity and quality of turbid water discharged with equal velocity into them. The observer must, however, here again take modifying circumstances into account. As far as the mere striking of a body of river-water against a still fluid is concerned, it will necessarily receive the greatest check from the heaviest or most dense; and hence any given river would be more checked by rushing into the sea than into fresh water, if it were not that in the former case it ran over it, while in the other it ran into it, and therefore received the greatest check, on the same principle that a river is more retarded by running into sands than by flowing over them.

The different density of the river from the sea water should also be attended to on another account. The greater the density of the fluid, the greater would be the difficulty of detritus of the same weight, size, and shape passing through it. Hence the same kind of detritus would take a greater length of time in passing through sea than fresh water, both being of the same depth, and therefore would be a longer time exposed to the chances of movement in the one case than in the other. It also follows, that detritus, which would just settle when the velocity of a turbid river was checked by flowing into a body of fresh water, would not so imme-

diately settle from a turbid river discharging itself into the sea. In the first place, the river would not experience the same amount of check; and in the second, the detritus would afterwards have to pass through a denser medium to the bottom, even in the case where the river and sea waters were somewhat mixed. These hints will be sufficient to direct the attention of the observer to several modifying circumstances, and others springing from them will readily present themselves to his consideration.

An observer desirous of making direct experiments on the depth to which the turbid waters of rivers may extend, either near their embouchures, or flowing some distance out to sea, should procure water from different depths by one of those instruments contrived for such purposes, and carefully ascertain their relative specific gravities, in order that he may not attribute the presence of merely discoloured surface-water at a distance from land to a wrong cause. He should also take the temperatures of the waters at different depths, as these also may assist him in estimating the relative densities of the waters. By these means Captain Sabine came to the conclusion that the discoloured waters of the Amazons flowed over the ocean to the distance of three hundred miles from its embouchure.

e. It will be evident that if there be any great movements in the waters of the sea, they will transport a great proportion of the detrital matter, held in mechanical suspension by the rivers discharged into them, in the direction of the prevalent movement. Now there are two great movements in the waters of the sea, more particularly felt on coasts and in shallow water; the one

caused by tides, the other by prevalent winds—by the evaporation of an inland sea communicating with the ocean, greater than the supply of water it receives from rivers, which causes a rush of water from the ocean into it—and perhaps also, to a certain modified extent, by the motion of the earth on its axis. Of the latter, commonly termed marine currents, many act in constant or nearly constant directions, while some drive part of the year in one direction, and during the other part in one directly opposed to it. The movements caused by tides for the most part act in directions opposed to each other; so that the same great body of water is moved backwards and forwards, a few hours one way and a few hours the other, local causes producing local variations both as to the relative times of the opposite movements, and in their intensity.

f. The observer should direct his attention to the various local circumstances which may influence the deposits in a delta formed in the sea, more particularly with reference to the disturbing movements above noticed, and to the exposure of the coast to the action of the waves, care being duly taken to estimate the value of the depth of sea into which the delta is protruded. If there be little movement from tides and currents, he would expect to find, under otherwise equal circumstances, that there would be a tendency to form a more muddy deposit on the margins of a delta so situated, than where tidal or other movements were brisk. Due attention should be paid to the influence of wood and small trees borne down a river, since they become entangled where the velocity of the stream is unable to keep them from doing so, and cause obstacles on which

detrital matter accumulates. The exterior of a delta is also greatly modified by the piling action of the waves, when such takes place, as will be noticed in the sequel.

g. Among so many modifying circumstances, it would be difficult to afford the observer very direct information as to any general character of the resulting deposits obtained from detrital matter thus forced into seas. They will necessarily be more complicated in one locality than another; inclined beds may be produced by the friction of the rivers on their channels, which necessarily are disposed to shift, while more horizontal beds result from the quiet deposit of sediment from mechanical suspension in the water. The occurrence of gravel or coarse sand in such deposits will necessarily be rare in proportion to the extension of the delta, since the general velocity of the discharged waters is diminished according to such extension, both from the increased line of level or nearly level channel, and from the frequent checks offered to the onward course of the river, which tend to split the main streams into numerous minor branches.

h. Attempts have been frequently made to calculate the quantity of solid matter borne down by any given river, either into the sea, or in some particular part of its course. When we narrowly examine the manner in which the experiments have been conducted, there are few results which can in any manner be considered as approximating to the truth. When we consider that there are two processes by which detritus may travel onwards in a river, the one pushing, the other transporting by mechanical suspension, both of which frequently co-exist in the same river, it will be obvious

that observations made only on the one cannot give the amount of both. The relative amount of the pushing process can scarcely be estimated except by observing the time required to fill up or occupy any given space, such as the accumulation necessary to fill up a space of given depth, breadth, and height, or the time required to advance any given delta a given distance; the slope of the delta, and the depth of water into which it is protruded, being accurately known. Much might therefore be done at a delta, if all the matter there collected resulted from the pushing process: but as part of such accumulations is generally due to a deposit from turbid waters checked in various places, we do not obtain satisfactory results. It should be recollected that the same detritus which is held in mechanical suspension in the higher part of a river-course may fall to the bottom, from diminished velocity of the stream, in another and lower part of its course, and be then pushed onwards by friction: and this power may finally cease to act from still further diminished velocity. So that it by no means follows, if the quantity of matter mechanically suspended in a given river, in a part of its course distant from the sea, could be accurately known, that such matter was actually borne into the sea, even when there should not be any intervening lake to arrest its progress.

The usual process of estimating the quantity of earthy matter mechanically suspended in a turbid river, has been to ascertain the figure of its bed at the desired place, and its velocity, which is supposed to give the quantity of water which passed that given spot in a given time. Certain measures of the water are then

obtained, such as a cubic foot, and the quantity of sediment from it ascertained. Sometimes these measures are obtained from one or two, or even three different parts of the river; but more frequently only from one, somewhat centrical. In the first place, the laws by which a river is retarded in its course by friction are not correctly known, without which the exact quantity of water passing down a river cannot be ascertained; and in the second, we do not yet know from whence to take up given measures of the water, so that anything like an approximative mean of the detritus moving forwards in the water can be obtained.* An observer will therefore experience great difficulty in estimating the amount of detritus carried by any given river to the sea, or in given parts of its course. This, however, should not prevent him from doing the best he can with the existing knowledge on such subjects; for if he record the various precautions he may employ to guard against error, his observations may not eventually be thrown away.

i. The modifying influence of tides should be duly attended to in those situations where they flow up deltas to different distances, as is the case with that of the Ganges. The accumulating power of mangrove trees in tropical countries in similar situations should on no account be neglected, since it is frequently very considerable.

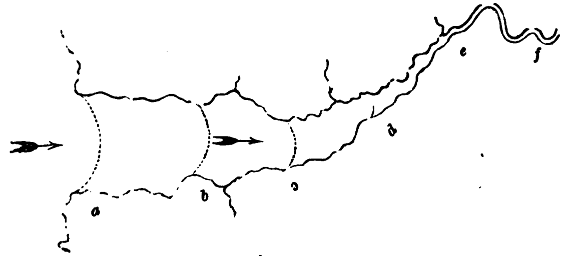
k. It can be scarcely necessary to remind the observer that all rivers do not form deltas where they flow into the sea; and that, on the contrary, some have

* For remarks on this head see "Researches in Theoretical Geology," by H. T. De la Beche, p. 68.

large wide embouchures into which tides freely flow. Local circumstances necessarily produce a great variety of effects between those observable in the open mouth of the St. Lawrence, and in the deltas of the Indus or the Ganges. The observer will find that the proportionate number of open-mouthed rivers is greatly less on the coasts of tideless or nearly tideless seas, and of great lakes, than on the shores of the ocean; and that where large estuaries exist, the tides are strong, all other things being equal. The amount of detritus pushed forwards by friction must greatly influence the power of a river to form a delta. The quantity of detrital matter borne to the sea must greatly depend upon the kind of country which the rivers traverse; but, all other circumstances being equal, those rivers which can push forward the heaviest and largest detritus would most readily accomplish the formation of a delta.

l. The exposure of a river's mouth to the full force of the tidal wave, if the power of the river and quantity of detritus borne down be not relatively very considerable, greatly tends to keep an estuary open. If the annexed sketch (Fig. 48) represent an estuary open to

Fig. 48.



a tidal wave, then the height of the wave will be greater at *a*, where it strikes the mouth of the estuary, than in the open sea; and it will be still higher at *b*, and run with greater velocity than at *a;* because the same quantity, or nearly the same quantity of water, is driven into a narrower channel. It thus goes on increasing in height and velocity until it loses the propelling power of the water behind it, arising from the ebb of the tide at the mouth of the estuary, and becomes checked in velocity and lowered in height from the want of support behind it; so that the friction on the sides and bottom of the channel, which always retarded the waters to a certain extent, the rise of the channel itself, and the force of the pent-back river-waters, come forcibly into action, and the tidal wave proceeds no farther. We may, for the purpose of illustration, suppose that the tidal wave increases in velocity and height in the estuary represented above (Fig. 48) from *a* to *d*,—*b* and *c* being intermediate stages,—and that from *d* it decreases by *e* to *f*, where it is finally stopped.

The observer will at once perceive that the transporting power of a body of water so circumstanced will vary considerably in different places. The turbid waters of the river, of which the estuary forms the embouchure, are necessarily discharged into this mass of tidal waters, sometimes swept outwards, sometimes inwards, according to the ebb or flow of the tide. So long as the agitation of the estuary water is sufficient to keep it mechanically suspended, the fine detritus cannot be deposited except in those situations where diminished agitation will permit it to fall down. It can, however, only permanently be brought to rest in such

situations on the shores as are not exposed to the disturbing power of the breakers; and thus, unless the annual amount of accumulated mud or silt be greater than the annual amount carried off by the action of the breakers in such places, there will be no permanent increase. Hence, notwithstanding the general muddy character of the shores of estuaries, no permanent increase takes place, except under the above circumstances, or when the breakers pile up beaches on low shores, and thus render tracts of country behind secure from their ravages; so that such tracts would be filled up by sediment, if small channels of communication were open, as frequently happens, to the height of the estuary waters.

m. The power of the river to push detritus forward necessarily receives a check proportionate to the force of the flood-tides, which may even force back such detritus by friction. As the tides vary in power, and the like happens to the river, according to the quantity of water in it, there will be a space where gravel or sand, as the case may be, is accumulated: these are frequently known by the name of *bars*, and their situation depends on a great variety of local circumstances, which an observer will take into account when he has any particular estuary or river under examination.

Much detrital matter will, however, under all circumstances be committed to the body of estuary waters. Now, although the strength of tides in such situations is sufficient to keep a great quantity of it mechanically suspended, so as to render the estuary waters highly turbid, it is clear that if a deposit did not take place somewhere, such waters would eventually acquire so

much fine detritus as to be mere mud. The observer will find that the heads of estuaries have a tendency to fill up, as also the sheltered places; but that, generally speaking, the deposits at the heads are more gravelly and sandy than those of merely sheltered places, into which gravel and sand are not driven by a tributary stream. To illustrate this, let the annexed sketch

Fig. 49.

(Fig. 49) represent an estuary; then it will generally be found that the deposit at the head, *c*, is more gravelly or sandy, particularly in its lowest parts, than in the merely sheltered positions, *a* and *b*. And this arises because the detrital matter pushed forwards by the river, *d*, has been arrested at *c*, while in the sheltered spots, *a* and *b*, the sediment has been deposited from the turbid waters checked in their movement, and rendered more or less still according to circumstances.

Notwithstanding the deposition in the sheltered places on the sides of estuaries, and at their heads, a time must come, supposing a large amount of detritus to be brought down during a series of ages, when the sheltered spots will be filled up, and an increase take place only at the head. The quantity of fine detritus

required to fill up the sheltered places, even supposing the increase at the head to be a constant quantity, will go somewhere, and would render the estuary waters gradually more turbid unless deposited. Now the deposit may either take place in the channel of the estuary itself, or be carried into the sea to be there distributed. The first supposes that the velocity of the tides is insufficient to cut it up when deposited, or prevent its being deposited at all; and the second, that it can escape into the sea.

Some estuaries are so long,—such, for example, as that composed of the Bristol Channel, and its continuation up the tidal waters of the Severn,—that the *surface-waters* at their mouths, if we may use the expression, are not turbid at any time of tide, while the whole of the turbid waters are apparently driven backwards and forwards by the tides in the more inland parts. To enable turbid waters to escape seaward under such circumstances, they must necessarily have a movement in such directions. Now the mere movement of the waters in a long estuary could not produce this effect if the line of turbid water did not come, at the lowest state of the ebb-tide, outside the estuary altogether, when probably, from the general movement of the tide on the open sea-coast, a portion of such turbid water would not again be forced into the estuary, as may be well observed in short estuaries, or those where the line of turbid waters always extends into the sea at low ebb.

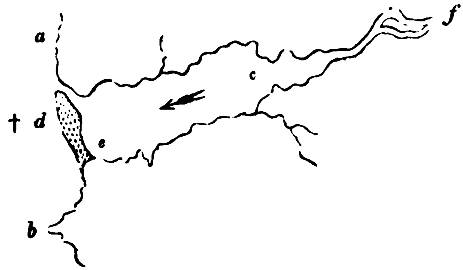
We have, however, to consider that the water of an ebb-tide in an estuary has all the waters of the rivers and streams, pent back by the flood-tide, added to it. Upon their relative weights or specific gravities would

depend the power of the pent-back river-waters to float upon or sink beneath the sea-waters forced into the estuary; which themselves, or at least such portions of them as are washed backwards and forwards by the tides, become brackish and increase in freshness as they approach, and become agitated with, the rivers and streams. There is, therefore, complicated action; and the inquiry ends with the power of the detritus to escape from the long estuaries seaward beneath the clearer waters above, either by the friction on the bottom of the surplus accumulated waters flowing seaward, so that the general sea-level be maintained, or from the same waters being rendered heavier by the amount of detritus mechanically suspended in them, so that they keep the bottom and remain unseen. It will be obvious that the observer may in a great measure discover how far this may be the case, by taking water from different depths in different parts of a long estuary at marked and various times of tide, and by examining their relative specific gravities and the quantities of detritus they may contain.

n. We have not space to enumerate the various modifications an estuary may sustain. It will be sufficient to notice those cases in which, at the meeting of estuary waters with the main sea, the power of the tides is unable to prevent a deposit of detrital matter where the ebb-tide of the estuary is checked by its entrance into a sea, the tidal movement of which is not prolonged in the direction of the estuary ebb, but takes a course frequently at right angles to it. When such a deposit takes place, the accumulation across the mouth of the estuary, usually termed a *bar*, is greatly assisted,

and eventually greatly modified, by the piling action of the breakers falling on the coast generally. Let the annexed sketch (Fig. 50) represent a line of sea-coast,

Fig. 50.



a b, from which an estuary, *c*, runs nearly at right angles into the land, and terminates in the river, *f*, that discharges a considerable quantity of detritus into it, particularly during freshes or floods. Let us further suppose that the ebb-tide has commenced in the estuary, as it usually does, after the ebb has acquired considerable strength along the line of coast, *a b*, and that the latter runs in the direction of the arrow, *d*; then the turbid estuary waters, descending in the direction of the arrow in the estuary, would meet the general movement of the sea on the coast nearly at right angles, and they would consequently receive a check where they attained the line of coast, and a deposit, *e*, would be gradually effected in such situation, which would be greatly modified and assisted by the piling action of the waves falling on the general line of coast, *a b*, as will be noticed under the proper head. There are few rivers which have not, from these causes, bars at their embou-

chures: they are greatly modified according to local circumstances, to which the observer must direct his attention. In some rivers the bar is so considerable as greatly to obstruct the navigation into them, and even, in extreme cases, may be said to close up rivers which would otherwise possess great commercial advantages. In the case above supposed, the estuary is necessarily short, or one where a large proportion of the turbid waters escape into the sea at every ebb-tide. The observer should note the kind of deposits which, from the check of the bar, take place in the estuary, as also the kind of bottom in the sea immediately outside, or seaward, which he will generally find most clayey and muddy in the direction of the ebb-tide along the coast, because the turbid waters, from obvious causes, there part with the greatest part of the detritus they may contain.

o. As the observer cannot directly view the manner in which detritus is now deposited at the bottom of the sea, he can only approximate towards such knowledge by directing his attention to those circumstances which must influence products of this description. From the operation of geological causes, beds of clay, sands, and the like, are indeed brought to light, and are inferred to have been formed beneath the sea, because they abound with the remains of marine creatures, even of those found in the seas of the present day, and therefore certainly known to be such; and thus opportunities are afforded for studying the effects produced. This will not, it is obvious, afford an observer the necessary data for judging of the extent to which given marine deposits can take place, of the mode in which

they are accumulated, or of the subordinate causes which may greatly influence them. Above all, it will not teach him the extent to which the forces daily in action on the surface of the globe can account for those masses of detrital rocks, of different geological ages, which occur in various parts of it.

p. By sounding in the usual manner with the lead, we have direct evidence that the bottom of the sea consists of mud, silt, sands, gravel, marine shells both broken and entire, portions of corals, and the like. Now, as from geological facts we possess evidence that the relative positions of dry land and sea have not been constant, but that, on the contrary, a large proportion of the present dry land once constituted the bottom of the sea, while dry land must frequently have been submerged beneath the latter, these events having often occurred in the same parts of the earth's surface, we cannot be certain that the mud, sands, and gravel found beneath the present seas were deposited there from such seas during the existing relative positions of sea and land, in any particular area under consideration. It may be highly probable that the mud, silt, and the like, found beneath the seas which bound any particular tract of dry land, may have been carried to their present positions by those movements in the seas that are now observable in the same situation; but to feel assured that we do not fall in to unperceived errors on such a subject, we must first take all the circumstances of such sea-movements into consideration, carefully weigh the whole of the evidence, and then see how far such movements could carry the observed mud, silt, sands, or gravel, as the case may be, to the localities

where they are now detected. Such observations, no doubt, require considerable care; but their geological importance is so great, that those who possess good opportunities, as often happens to naval men, should on no account neglect them. It is to the want of sufficient data on this head that we may attribute those loose generalizations so often hazarded in geological treatises and memoirs, and which, when closely examined, seem to rest on little else than the good-will and pleasure of their authors.

q. From various causes, previously noticed, detritus derived from dry land is committed to the sea. It is necessarily distributed over greater distances by the movements produced by tides and currents, than it would be if the waters of the sea were perfectly stationary. The tidal wave is only a great undulation causing little appreciable horizontal movement, except on coasts and in shallow waters, where, viewed generally and by itself, it produces a backwards and forwards horizontal motion of the same waters for a distance of about sixteen to twenty miles; local causes sometimes extending this distance, at others diminishing it. Marine currents act more extensively, and traverse the ocean in different directions; though it may be stated that a larger mass of sea-water is moved from East to West in the Equatorial regions than in any other direction in any other part of the globe. The depth to which such currents extend, when their surface velocity is known, has not been ascertained; though if we take surface causes for their origin, such as prevalent winds, the rush of water from the ocean into an inland sea, to restore the loss from evaporation, and the like, we

cannot anticipate that they will be very deep. This is a subject to which the attention of the observer is strongly invited: the only direct experiment made, that we are aware of, is that recorded by Captain Becher, who found in lat. 15° 27′ 9″ N., and in long. 17° 31′ 50″ W., that a current moving at the rate of 0·75 per hour had the same velocity at the depth of forty fathoms as on the surface.

r. When an observer is desirous of estimating the direction and extent to which detritus, derived from any particular line of coast, is drifted by movements in the sea, he should, after duly noticing the quantity and kind delivered into the sea on such line of coast, proceed to examine the direction and extent to which tidal movements may bear it, taking into account any probability of a movement sufficiently strong to shove the sands and silt forward on the bottom. In fact, he should endeavour to ascertain if the pushing process caused by the friction of the moving water, and the simple transporting action by mechanical suspension, do or do not co-exist in the streams of tide; because, if they do, the resulting deposit would necessarily be more complicated than if one only were in force. If a stream of tide were sufficiently strong, it would push detritus before it when no appreciable quantity of detrital matter was disseminated through its waters; while, on the other hand, deposits may be effected from gently moving waters, more or less charged with such matter, which are unable to move forwards the mud, silt, and sands on the bottom. As in the case of rivers, we do not correctly know the laws which regulate the retardation of moving sea-waters by friction on the bottom

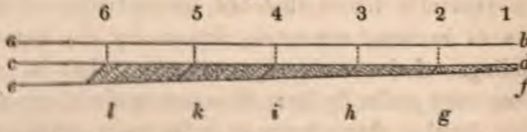
over which they pass, and therefore are unable to calculate the value of such friction, when the depth of water and surface velocity are known. Hence direct experiments to clear up this subject are particularly desirable. The observer should bear in mind, that sea-water being heavier than fresh water, there will necessarily be a difference in the amount of retardation by friction, and consequently of friction itself, between the two, even when all other things are equal.

s. Facts connected with soundings, as they are termed, or those depths which are attained by a line of one hundred or one hundred and fifty fathoms in length, would seem to point to a certain pushing power of the tidal movements round coasts, probably combined with that action of waves which, as it were, shake up the finer sediment from the bottom in minor depths, and thus throw more detritus into the power of tidal movements than they would otherwise possess. In many instances also, marine currents, arising from other causes, may assist in producing the effects about to be noticed. It is generally found that the seaward edge of those tracts of bottom, commonly known by the name of soundings, shelve suddenly outwards; that is, after sloping very gradually from the coast to the above-mentioned depths, they plunge at a far more considerable angle seaward. Let the line *a a*, in the accompanying and greatly exaggerated section (Fig. 51), represent

Fig. 51.

the surface of the sea, and the inclined line beneath it that of soundings extending from the coast, *d*, to the deep sea, *b*. Then it will be generally found that, after continuing gradually to deepen, the soundings will more suddenly plunge at *c*, where we suppose a depth of about one hundred fathoms, into deep water. In these cases, which are well shown on the outer verge of soundings connecting France with Norway, and including the British Islands, where the line of two hundred fathoms is but a short distance outside that of one hundred fathoms,* there is much to remind us of the form in which detritus is arranged in some deltas, if we make a section along their length. The supposition that tidal movements can produce this form at considerable distances from the land may, at first sight, appear inconsistent with the relatively small backwards and forwards motion noticed above. This difficulty seems, however, more apparent than real. Let *a b*, in the annexed section (Fig. 52), represent the surface of a por-

Fig. 52.



tion of sea exposed to tidal movement, so that the point 1 moves to the point 2, 2 to 3, 3 to 4, and soon, during the ebb tides, and the respective points move back to their respective places during the flood; so that, in fact, there is a to and fro movement of the whole, to the

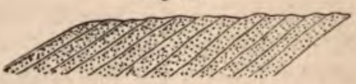
* See the chart and remarks in "Researches in Theoretical Geology," p. 190.

amount of the distance from 1 to 2, 2 to 3, &c. There would be modifying circumstances, to be noticed hereafter; but, for greater simplicity, we will now neglect them. Let the line *c d* be the depth to which the tidal movement has the power to shove superficial and given kinds of sand, silt, mud, or the like, backwards and forwards; and let *e f* represent a bottom of solid rock sloping from the land to the depths of the ocean. If we now suppose detrital matter deposited and to a certain extent levelled from *f* to *g*, any additional quantity would be thrown over at *g*, by the to and fro movement of the portion of water, comprised between 1 and 2, to the space 2, 3, which in its turn moves in a similar manner to the space 3, 4; and so on. The given detrital matter brought over the steep slope *g* could not be again moved back to *f;* for it would not only be beneath the line of shoving power *c d*, but it would also require a power sufficient to push it up the steep slope *g*,—one which, under the circumstances enumerated, could not exist. Hence, if detrital matter, capable of being pushed about by the tidal movement, at the depth *c d*, be constantly added on the side *d f* (that of the land), the same forces will continue to level the upper part to a certain extent, accumulations of shelving beds being added to the seaward steep slope, which will go on advancing in the direction *h*, *i*, *k*, *l*, and be more slow in such advance in proportion to the increased depth of the water.

This explanation is merely thrown out as a hint to the observer, who has to consider that the movements of a stream of tide are greater in proportion to the proximity of land, from the resistance opposed to the tidal

wave under such circumstances, and therefore that the distances 1, 2, 3, 4, 5, 6, would not be equal, but decrease seawards, or from 1 to 6 ; as also that the line of soundings is not horizontal, but inclined at a very small angle ; and that the whole deposit may be greatly modified by the accumulation of fragments of shells, corals, fish-bones, &c. over fine detrital matter ; thus preserving it from that movement which could just disturb it. Many other modifying circumstances will also strike him, if he direct his attention to this subject, which has been more especially introduced to see how far a series of somewhat highly inclined shelving beds of sand or silt, such as are represented in the annexed section (Fig. 53),

Fig. 53.



may in this way be produced ; and, consequently, how far the accumulation of soundings, supposed to be in progress in the present day, may account for sandstone and schistose beds so arranged, that, if we are to suppose them to have been deposited horizontally above each other at the bottom of the sea, we must also suppose one of far greater depth than, in all probability, now exists in any part of the ocean, or which we should conceive ever has existed.

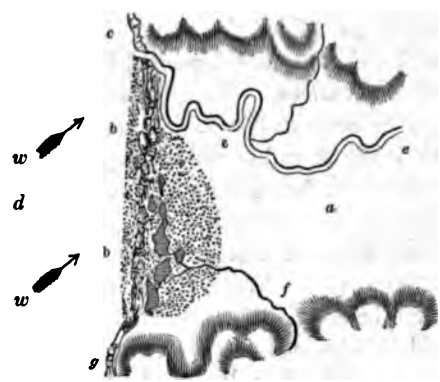
t. Deposits from marine currents, in which detrital matter is disseminated, would necessarily be more extensive than those from tidal streams, if detritus were discharged into them to an equal extent, since they flow over far greater surfaces. We might hazard some conjecture as to the distance to which mud or silt would travel

by such means, if experiments were made on the time it took for fine disseminated detritus of different kinds to settle at the bottom of *sea-water* a yard or any other convenient measure in depth, and also knew the depth to which a given current, moving with an ascertained velocity, extended; but, unfortunately, respecting all these essential data we are as yet uninformed. While on this subject, it may not be without interest to consider how far the increased density of water, in the lower parts of the deep ocean, from superincumbent pressure, would retard the fall of the finest detritus, supposing such to be brought to, and deposited from, marine currents in such situations. To ascertain how far detrital matter may be contained in marine currents, in various parts of their course and at various depths, not only the proper instruments for taking water up from the required situations are necessary, but also such opportunities as the naval man can almost exclusively possess, and these not frequently. Water which may be thus procured should be carefully bottled, and sufficient quantities should be obtained to detect the small amount of detritus which probably will alone be found in it.

VII. *Accumulation of detritus on coasts by means of breakers.*—*a.* On those parts of coasts which are nearly on a level with the sea when tideless, or which rise little, if at all, above high-water in tidal seas, the observer will find that there is a tendency to force shingles and sands on shore, long lines of shingle-beaches or sandy dunes being accumulated in front of level tracts of country so situated. Such beaches or sandy dunes not only protect lowlands from the inroads of the sea, but frequently modify the lowlands themselves, either

by preventing the minor drainage of the country, which thus readily forms into marshes, or are the cause, if composed of sand, of great inroads of such sand, which is blown over the neighbouring districts; whole bodies of it even advancing at a slow but certain rate, as is well seen in the line of sandy dunes extending from the mouth of the Garonne to the district of Bayonne. Let the annexed sketch (Fig. 54) represent a tract of low

Fig. 54.



level land, *a*, bounded seaward by a shingle or sandy beach, *b b*, which protects it from the ravages of the sea, *d*; and let *e e* be a river which delivers itself into the sea between the cliff *c* and the beach *b*, while *f* is a minor stream unable to pierce through the beach *b b*, and therefore loses itself in pools and marshes behind it, partly percolating through the beach, and partly soaking and rendering the ground marshy towards the river *e e*.

The observer, if placed in such a situation, which we

have supposed, for more easy illustration, to be comprised within a somewhat limited area, should endeavour to discover the manner in which the beach itself is produced. As beaches travel in the direction of the prevalent winds, he should ascertain the kind of pebbles, if it be a shingle-beach, composing the one before him. If he find them such that they are evidently rounded fragments of rocks derived from the cliff *g*, and others in the same direction, he will conclude that they have been brought from thence by the small oblique action given to waves by prevalent winds striking the coast in a similar direction. In the sketch before us (Fig. 54), these winds might strike the line of coast in the direction of the arrows, *w*, *w*. If this were the case, the drift would continue towards the cliff, *c*, and would only be prevented from reaching it by the force of the river, *e e*, which is supposed strong enough to drive the accumulating pebbles outwards. It will be obvious, if this were the state of things in the above situation, that the area, *a*, may not only have been exposed to many changes during the production of the beach, *b b*, but may still continue to be so. As all areas so circumstanced vary according to local conditions, the observer should direct his attention to such conditions, carefully estimating which may have most influenced the present conditions of the particular area examined.

The chief geological value of observations of this kind is to see how far they may be found to illustrate those alternations of marine, estuary, and fresh-water deposits, often found, particularly among the supracretaceous or tertiary rocks. The observer should endeavour to obtain sections of such flat lands, which may

often be seen in deep drainage cuts; and he should collect organic remains, if he can, (in the manner noticed in the sequel,) from any beds of gravel, clay, or sand which may be thus exposed.

With regard to the deposit of detrital matter in such situations, much would depend upon the power of the river, *e e*, to keep a passage open into the sea: if a heavy gale of wind, acting on shore, force up a bank against it, the river would overflow the lowlands; and if charged with detrital matter, some part of it might be deposited on them. The minor stream, *f*, would constantly add detrital matter brought down by it to those places where it loses both its pushing power and transporting velocity, and might be the cause of a great mixture of vegetable substances, grown in the ponds and marshes, with sands, silt, and mud.

b. When sands are blown from sandy dunes inland, as commonly happens, the observer should endeavour to ascertain the amount of land thus covered, (and it is often considerable,) the rate of advance, and the general thickness and character of the resulting deposit; noting alternations of vegetable matter that mark the various surfaces which, for a time, were sufficiently stable for the growth of plants, and which became respectively covered by the sand-drift.

c. Sand-drifts are not always confined to those low tracts of land between which and the sea there are dunes affording the necessary dry sand. Sand-drifts sometimes take place at the bottom of deep bays, exposed to heavy waves rolling over shallow sandy depths before they reach the coast. The observer will find several examples of this fact on the coasts of Cornwall and

Devon. The sands in such cases are very frequently little else than comminuted sea-shells. The resulting deposits are geologically interesting, particularly as land-shells and the bones of land-animals are often over-whelmed by new drifts. The sections also are inte-

Fig. 55.

resting, being sometimes such as above (Fig. 55); *a* being the drift-sand, and *b* the rock of the hill against which it is drifted.

VIII. *Chemical deposits from fresh and sea waters.* —As waters from springs are not pure, but contain various substances in solution, and as these are the chief sources whence rivers are supplied under ordinary circumstances, it follows that in large rivers into which many tributaries deliver themselves, and in lakes, there may be numerous substances in solution, which, when mingled together, may have a tendency to act upon each other and produce new and insoluble compounds.

a. When an observer suspects that calcareous or other substances are thrown down from waters in which they were previously held in solution by the necessary quantity of carbonic acid or other substances, as the case may be, he should carefully obtain water from the rivers or lakes under his examination, and see if such substances are really present in their waters. If he be unable to analyze it himself, he should put the water into a clean bottle, immediately seal it up carefully and

tight, and forward it to some experienced chemist for examination.

b. It would be highly desirable to ascertain the approximative amount, as well as kind of substances, held in solution by the waters entering different lakes, and then obtain those of the waters at the discharging outlets, in order to estimate the kind and amount of chemical deposits, if any, which may take place in such lakes. If these latter be shallow and extensive, evaporation alone might cause appreciable effects, particularly in warm latitudes. If calcareous matter be considered to be left in the waters of the lake, due regard should be paid to its probable consumption by the shelled molluscs inhabiting it, and also to the accumulations that may thence arise.

c. Observers would gradually accumulate a large amount of valuable information on this subject, if, when unable to analyze waters themselves, they collected with the necessary care, for examination by proper persons, those of various rivers which discharge themselves into the sea. If this were done for any particular line of coast, not neglecting the minor streams, which, collectively, are as important as the larger rivers, we might obtain an approximative knowledge of the general amount of the substances, as also of their relative kinds and proportions, thus transferred annually from the dry land so drained into the sea. It would be highly interesting to know, if it be only approximatively, the amount and kind of matter thus thrown in a state of solution into the seas which surround the British Islands.

d. It may be very true that various rocks, supposed

to have been formed chemically beneath the waters of the sea, may have been really so produced; but it remains to be seen whether we must not employ the term *sea* in a more enlarged sense than is usually done by geologists. At present it seems to be supposed that the saline contents of the sea have always been such as are now discovered in the waters of the ocean. This may be true also, though there are reasons which may lead us to a contrary opinion; but neglecting these for the present, it may be observed as a curious fact, that hitherto no direct experiments have been made to discover under what conditions calcareous or other deposits, resembling those of known rocks, can be produced in *sea-water*. The line of research will readily present itself to those possessed of competent chemical knowledge; and it would be highly important to ascertain the extent to which the present saline contents of the ocean would carry us in accounting for those large masses of calcareous matter, which we consider to have been of marine origin, because in them we find the remains of shells analogous to genera, and sometimes to species, which now exist in the sea. The presence of such exuviæ by no means proves that the seas inhabited by the creatures of which they constitute the remains, were precisely the same, as respects saline contents, as those of the present ocean; since we know that such creatures can be brought to live in a medium which may vary considerably in this respect. Moreover, the waters of the Mediterranean are more saline than those of the Atlantic; and yet several species of molluscs are common to both. It would seem that waters may be ex-

ceedingly saline, and even contain a different proportion of certain salts, as is the case with the Caspian, and yet molluscs thrive in them.

e. As siliceous deposits take place from some thermal springs, search should be made in the vicinity of such springs, particularly when very hot, for the purpose of observing how the rocks to which siliciferous waters may have access, may be influenced by them ; the mode in which sand may be agglutinated by these means; as also the time required to cover vegetables with a sufficient coat of silica to arrest decomposition. Experiments to ascertain the latter point would be highly interesting; since there exist siliceous fossil vegetables, which would seem to show that plants may be so speedily covered and impregnated with silica as to stop that decay which might take place in a few days, particularly in tropical countries.

f. The angles at which successive coatings or beds of substances, analogous to those of rocks, have been deposited either from natural or artificial solutions, should receive attention; since they may afford us information as to those we may allow for original deposition, and for disturbance after deposition, when the dislocations and fractures of any particular country are under examination.

IX. *Manner in which organic remains may be entombed in rocks now forming.*—If the distribution of animal and vegetable life over the face of the globe be important to the study of organic remains generally, the mode in which the exuviæ of such animal and vegetable life may be now entombed is not less so.

a. There can be scarcely any one who has seen sec-

tions of ground laid open for roads, ditches, or other purposes, who has not observed that the shells of the common snail and other land-molluscs are often found immediately beneath vegetation, while the bones of reptiles, birds, or quadrupeds are exceedingly rare in the same situations. The rapacious and scavenger animals in general either devour the bones with the other parts of the creatures they destroy, or eat up the bones of dead animals which others have left, and which rarely escape the constant search made by numerous creatures for such offal; consequently few bones remain on the surface of land to be covered by the soil resulting from animal and vegetable decomposition, or from earth drifted by different causes over them. The chances therefore are against the preservation of the bones of animals immediately beneath terrestrial vegetation from ordinary natural causes. With the solid parts of land-molluscs, such as the common snail and others, the case would be different, for many of these molluscs bury and conceal themselves in holes in the ground; and as multitudes die in such situations, and their fleshy parts are there consumed by various small creatures which do not attack the shells themselves, these latter remain to be covered up by earth washed by rains into the holes, and eventually are for the most part preserved entire, or nearly so, in the common superficial soil of dry land.

b. To estimate the manner in which the bones of terrestrial animals may be entombed on dry land under circumstances which may so far be considered ordinary that the necessary conditions exist in numerous parts of the earth's surface, the observer should direct his

attention to the accumulations of fallen fragments of rock and other substances, which take place at the bottom of open cracks and rents in rocks, at the base of precipices, and in caverns tenanted by different creatures, such as hyenas, bears, &c. Into the open fissures so common in many limestone districts, animals frequently fall, either in consequence of being chased by others, by unsuccessful attempts to leap over the fissures, or in consequence of the earth giving way on the edges by their weight. In alpine or cold countries, bridges of snow, stretched over fissures, frequently give way under animals attempting to cross them, and thus the latter are precipitated into the clefts beneath. Into these fissures fragments of rocks, earth, and sometimes plants, also fall from ordinary causes, and eventually entomb the remains of the animals, which may consist of their bones, as entire as they were after the fall; the fleshy parts of the creatures having been decomposed, or devoured by such birds as could descend into the fissure, and were unable to swallow or carry away the larger bones. If the fissure be in a calcareous rock, and there be a stalagmitical deposit of carbonate of lime, as not unfrequently happens in such situations, there may eventually be a compact mass of fragments of rock, bones, and calcareous cementing matter, filling part of the fissure. The observer, when he has any part of a fissure apparently so filled before him, should be careful to remove the bones with great care, in order that, if not conversant with comparative osteology himself, they may be sent to an experienced comparative anatomist in as perfect a state as possible, to decide how far they may be the bones of animals which still

exist, or be those of species no longer discovered living on the surface of the earth, and consequently the contents of the fissure be either referred to the present geological epoch, or to one anterior to it.

When an observer has a fissure filled in the manner above noticed before him, he should not content himself by abstracting bones only from the upper, or merely from the lower part; for it may have so happened that the fissure has continued open during a time in which there has been a change in the animals inhabiting the country; and, consequently, if the same causes had continued to operate, the remains of the earlier tenants of the district would be entombed in the lower part of the fissure, and of the later in the higher portions. Whenever opportunities offer, the observer should note the manner in which bones occur in the retreats of animals which carry their prey into such places in order to devour them;—the broken or other condition of such bones; and the accumulation of earth, animal fæces, fragments of rock, &c. which may cover them.

c. Large tracts of marsh-land, interspersed with small shallow lakes of water, would appear to be situations highly favourable to the accumulation of vegetable exuviæ. The leaves of trees which grow in such situations, falling on the various patches of water, take a horizontal position, forming a layer over the top of them. The leaves gradually soak up water, and are readily pressed down by the accumulation of other layers of leaves upon them, or sink from their own increased specific gravity to the mud at the bottom. An observer should attend to the mode in which the remains of vegetation are thus entombed, particularly in

tropical countries, where such accumulations sometimes take place on a large scale. He should also note the manner in which the exuviæ of aquatic creatures, frequent in such situations, become mingled with the remains of plants, as may also be the case with the bones of many terrestrial quadrupeds. He should by no means neglect to remark the manner in which the remains of animals and vegetables may be preserved in peat-bogs. These are often of considerable extent, and the facts connected with them highly interesting.

d. The fall of great quantities of ashes and cinders, discharged in some great volcanic eruption, would appear to be the cause of a greater sudden entombment of terrestrial animals and plants, with the probability of preserving their more solid parts entire, than can be obtained without the aid of moving water under other circumstances. The dust is sometimes so fine, that with the aid of moisture, which subsequently consolidates it, moulds of the internal forms of creatures may, under very favourable circumstances, be preserved, after decomposition has removed the flesh over which the dust and cinders first fell. Of this fact one or two remarkable instances have been observed at Pompeii, where moulds have been thus obtained of parts of the human form. Such cases must of necessity be exceedingly rare; but the preservation of the osseous remains of reptiles, insects, birds, and quadrupeds, would, we should conceive, be by no means so, particularly in the vicinity of the volcanic vent whence the ashes and cinders were discharged. Plants also, we should imagine, would be abundantly entombed under similar circumstances. Observers, therefore, favourably situated,

should not neglect the search of organic remains amid beds of volcanic ashes and cinders. In Pompeii and Herculaneum they have splendid examples of cities overwhelmed by substances discharged from a volcano, in which are not only found the osseous remains of man, but also an immense variety of his works, extending even to manuscripts, that have thus been preserved from the various causes of destruction to which they would have been exposed had they not been so enveloped.

e. Although the remains of animals and plants may thus, to a certain extent, be preserved on dry land without the aid of moving water, it is to deposits produced by this agent, and to others resulting from chemical changes in bodies of water, that we must turn for the preservation of the great proportion of organic exuviæ now entombed in mineral matter. The observer, therefore, should carefully direct his attention to the diversified manner in which this may be accomplished; so that when he studies the mode in which the organic remains of former geological periods occur, he may be enabled to judge of any difference or resemblance he may discover between them.

When treating of mechanical and chemical deposits effected in lakes and seas, or resulting from temporary floods over land commonly dry, we abstained from noticing that the greater part of such products contain the remains of animals and plants which have, from various causes, been enveloped by them. The fish, molluscs, and other inhabitants of a river, are, under ordinary circumstances, so adjusted to its velocity, volume of water, kind of bottom, and the like, that we can look to little

else than their natural death, which probably is rare, for the preservation of their remains in the mud, silt, sand, or gravel which may happen to accumulate in any particular part of such river. The solid parts of fluviatile molluscs are, perhaps, the only remains of creatures, constantly living in the river itself, likely to be enveloped by detritus thrown down in any part of its course. As, however, numerous rivers cut away their banks, when the latter are not protected by human ingenuity, the observer should direct his attention to the relative amount and kind of animal and vegetable remains that may be thus derived, and subsequently deposited in accumulations of mud, sand, or gravel formed by the river. He should not neglect the power of large trees washed out of the river-banks—as often happens in districts in their natural condition, unmodified by man—to alter the course of the river itself, particularly in level countries; and thus cause accumulations of detrital matter, mingled with organic remains, in such particular situations.

f. The fish in rivers, during floods, being exposed to a greater volume of water moving with increased velocity, seek shelter in situations where diminished velocity, caused by the friction of the water on the bottom and sides, enables them to retain their places. Fluviatile molluscs generally inhabit localities that are secure from the ravages of common floods; but when extraordinary floods sweep down the channel of a river, and leave accumulations of detritus in different situations, an observer would do well to examine such accumulations, and note the manner in which the shells of fluviatile molluscs may be enveloped by the detritus.

During river-floods which may be considered of extraordinary magnitude, numerous terrestrial animals and plants are borne onwards, and are not unfrequently left in those situations where the waters spread over flats and low grounds. An observer should endeavour to ascertain, when the waters have subsided, how far any animal and vegetable remains thus, as it were, cast on one side may become enveloped by sedimentary matter, and how far they would remain exposed to the ordinary chances of decomposition, from atmospherical causes, when uncovered by such matter.

g. The relative amount of organic exuviæ which may be entombed in mud, silt, sand, or gravel, by rivers in their courses, either under ordinary or extraordinary circumstances, is perhaps not great; though, from the change in the river-courses of some countries, more may be eventually accomplished in this manner than may at first sight appear probable. With respect to accumulations of organic remains among the detritus deposited at their embouchures, either in lakes or seas, the case is different.

The greater part of those sedimentary deposits which have been previously noticed as taking place in such situations, not only contain the remains of fluviatile and terrestrial creatures washed down the rivers and brought to rest, according to their relative specific gravities and other circumstances, but also the exuviæ of various creatures which live in the higher parts of the sedimentary deposits themselves, and which are either lacustrine, estuary, or marine, as the case may be. Under ordinary circumstances, many molluscs die naturally, and leave their solid parts entombed at various depths,

according to their respective habits, in the higher parts, for the time, of the accumulated detritus; or are killed by hunting-molluscs, which, after piercing their shells and sucking their juices, leave the solid parts or shells of their prey in the mud or sand, which eventually become still more deeply entombed by the subsequent accumulation of additional detritus.

The observer should attend to the various modes in which the remains of animals may thus be buried in mineral matter, carefully weighing those circumstances which may produce mixtures or alternations of terrestrial, fluviatile, estuary, and marine remains by the mere transport of organic and inorganic matter into given situations. He should recollect that the dead bodies of creatures borne downwards by rivers into lakes or seas may possess different specific gravities, and therefore would be brought to rest according to their state of decomposition at the time, and various other obvious circumstances; that mere bones and shells, unless the latter be so washed away from dry places that they float, would sooner be deposited, under the necessary conditions, than dead animals with their flesh upon them;—that plants or portions of trees would float or sink at unequal depths, according to their relative specific gravities at the time; and that they may be drifted greater or less distances, according to circumstances. In the case of, succulent plants, ferns, leaves of trees, and the like, he should mark the length of time and the conditions during or under which they can remain longest uninjured, and the mode in which they may be entangled on the skirts of a delta, the banks of an estuary, and other situations; noting

the different amount of succulent plants, ferns, leaves of trees, and the like, which may be accumulated among the roots of mangrove-trees in the tropics, or by other means in the colder regions of the globe. The observer should carefully estimate, from the facts he discovers, the various probable mixtures of organic substances with detrital matter in any delta or river embouchure he may study, weighing well the influence of any particular condition or conditions which may appear to modify the general product.

Sections occasionally present themselves in deltas when the waters are low, or when portions are raised by earthquakes. These should be carefully examined; and the mode in which organic exuviæ occur, if such are discovered, should be noted. An observer should endeavour to trace whether any organic substances he may discover in such situations have been quietly covered up, pushed forward by the river-waters, or brought to rest in a more sudden and violent manner; which last state is generally marked by a very irregular mixture of all the substances of which the particular deposit is composed.

Extraordinary causes, or floods, can scarcely do otherwise than produce a different kind of accumulation, at the entrances of rivers into lakes or seas, both of organic and inorganic substances, than ordinary causes. When, therefore, sections can be obtained under favourable circumstances, an observer should endeavour to ascertain the different effects produced by this difference in causes; recollecting that organic remains would probably occur in a different manner in one case than in the other, not only as regards their position in the detrital

deposit generally, but also with respect to the relative proportions of the various kinds of animals and plants entombed.

h. Organic remains are most probably enveloped by detritus of various kinds at the bottoms of lakes and seas under circumstances somewhat different from the preceding. The effects above noticed necessarily occur at the junction of lines of rivers with those of coasts; and if there were no antagonist forces in action, the various coast-accumulations of detritus, and of organic exuviæ mingled with them, would tend to form such constant additions to the superficies of dry land, that the areas of lakes and seas would as constantly diminish. Waves breaking against coasts tend, as has been previously seen, to wear them away under certain conditions, while under others they throw detritus from the sea upon the land. Breakers not only eject sand and pebbles, but also molluscs, fish, corals, and other organic substances, under favourable circumstances, upon coasts, where, accumulation succeeding accumulation, a mass of rejectamenta, varying according to local conditions, may be eventually formed. The observer should note the circumstances under which organic remains may be thus enveloped, carefully weighing the modifications which may be produced by local causes in such accumulations. It will be obvious that the surface of water exposed generally in lakes is not sufficiently extensive to permit that nearly constant supply of breakers which, under otherwise equal conditions, would heap considerable quantities of detritus and organic exuviæ on a sea-cost. Waves are indeed more easily produced, other things being equal, on the sur-

face of fresh-water lakes than on that of the sea by a given force of wind, because the liquid acted on in the one case is specifically lighter than that in the other: but then the waves of lakes, when equal in size, do not fall with the same weight as breakers on sea-coasts. Detritus being, however, thrown on the shores of lakes by breakers under favourable circumstances, an observer should examine any sections he can obtain of such accumulations, in order to mark the extent to which organic remains may be included among them.

i. We should anticipate, that in proportion to increased distance from the coast, accompanied by greater depth of water, and the consequent greater tranquillity which would prevail in the lower parts of a lake, there would be a more extensive and more uniform deposit over such organic exuviæ as may be there collected, than on the immediate coasts; and that these organic remains would commonly consist of the parts of creatures which generally inhabit the lower parts of the lake, mingled with the exuviæ of terrestrial animals that have perished in their attempts to cross from coast to coast, or have been carried far into the lake by river-floods. Probably also water-logged wood and the leaves of plants might be accumulated in the same situations.—As these deposits beneath the waters of lakes cannot be seen while forming, an observer can only approximate towards a knowledge of their mode of accumulation by carefully noting the conditions existing in any lake under examination, not only as regards the discharge of detrital matter into it, but also the envelopement of organic exuviæ by such detrital matter. It will be obvious that the conditions will not be

equal in deep and in shallow lakes: creatures which may merely fringe the shores of the former, may cover the whole bottom of the latter; and waves which would not disturb a deposit at the bottom of the one, would move detritus upon that of the other.

k. The foregoing observations in some measure apply to deposits enveloping organic remains beneath the sea at a distance from the coasts. In this case, also, an observer can only approximate towards a knowledge of the effects produced, by carefully noting those circumstances which may directly or indirectly influence them. Allowances must in like manner be made for shallow and deep seas, and the consequent modifications in the accumulations of detritus and organic remains formed in them. In lakes, whether formed of saline or fresh water, the superficies is not in general sufficiently extensive to come within the influence of any great variety of climate; and therefore the distribution of the fish, molluscs, and other creatures living in them, is not likely to be greatly modified by this cause. With the inhabitants of the sea, the case is altogether different: climate, though by no means the only modifying cause, does considerably influence their distribution.

l. We must refer to the works which treat of the distribution of animal and vegetable life over the surface of the earth for information on that head: it will be enough to state, that multiplied observations on this subject have shown that the same species are not necessarily discovered in any two given localities because the latter are alike as to climate and other conditions; but, on the contrary, if all animals and vegetables now existing on the face of the globe were suddenly to be

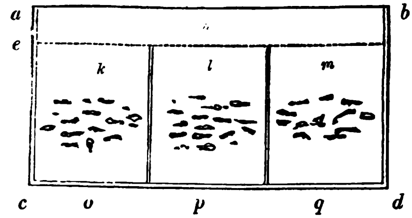
enveloped in a continuous bed of rock, that there would be little resemblance in the organic contents of the various parts at the distance of a few hundred miles from each other: consequently, though contemporaneous deposits of mud, silt, and sand are now taking place, and enveloping organic exuviæ around the British Islands and on the coasts of China, such deposits could not be proved to be contemporaneous by the organic exuviæ contained in each. Neither would any percentage of molluscs found in the deposits, and now existing in their respective neighbouring seas, prove their contemporaneous origin, though to classifications of rocks founded on this circumstance great importance has lately been attached, unless it can also be proved that the shores of the British Islands and those of China have been contemporaneously exposed to exactly the same conditions,—a circumstance that does not appear very probable.

m. An observer can make direct observations on the kind of bottom found beneath the sea, in those depths termed soundings, by means of the common lead employed for such purposes; and on the animal and vegetable life, at small depths beneath the immediate bottom, on the bottom itself, and in the sea, by dredging and fishing. Observations of this kind might be made more instructive than they have hitherto been to the geologist, if charts were constructed, not only exhibiting the depth and kind of bottom on given coasts, but also the force and direction of tides and currents which could transport detritus, the kind of detritus thus transported, and the parts of the sub-marine area tenanted by particular portions of animal and vegetable

life. By thus speaking, as it were, to the eye, more general and definite ideas are obtained than by pages of description. The scale of such charts would necessarily depend upon the amount of generalization attempted; but we can readily conceive that much general information might be conveyed upon a scale of one inch to the mile, that of the Ordnance Maps of Great Britain.

n. With regard to the mineralization of organic remains in various rocks—that is, the frequent change of the original matter of which the organic substance itself was composed when enveloped in mud, silt, or sand, as the case may be, into that of which it is often composed in rocks—we can readily imagine a series of experiments to be so conducted, though the great element, time, may be wanting, that much information may be obtained on this head. Suppose that an observer is desirous of forming some estimate of the value that should be attached to the percolation of water, charged with carbonic acid, through mud, silt, or sand, upon different organic remains contained in them, we imagine that he can do so by procuring a large vessel or box, of any dimensions or materials that may be considered most convenient, divided upon the principle sketched in the annexed cut (Fig. 56), which is supposed to

Fig. 56.



afford a vertical section of such a vessel or box, *a c d b*. Let this be divided into four compartments, of which three, *o p q*, are equal to each other and open at top, while the fourth, *h*, extends over them horizontally and is open at bottom. Let the compartments *o p q* be now respectively filled with mud, silt, and sand, of chemical compositions considered most convenient for the experiment, up to the line *e f*, and organic exuviæ, such as shells, fish bones, saurian bones, and the like, be placed in the mud at *k*, the silt at *l*, and the sands at *m*, taking care that such exuviæ be as much as possible of the same kinds, and placed in exactly the same relative situations in each compartment. If water charged with carbonic acid be now introduced into the compartment *h*, so as to fill it, it will tend to percolate through the substances in the compartments *o p q*, provided their respective bottoms be constructed of porous materials, as is necessary. In percolating downwards through the respective compartments filled with mud, silt, or sand, the carbonated waters will pass the organic exuviæ, *k l m*, and produce effects upon them according to their respective chemical compositions. If the vessel *h* be constantly supplied with water charged with carbonic acid in proportion as it percolates through the compartments *o p q*, and the experiment be continued a given time, such as a year, the condition of the organic exuviæ in each situation will show the amount of change that has taken place from the percolation of the carbonated waters. Of course the chemical composition of the mud, silt, and sands should be known previous to the experiment, in order that no sources of

error may arise from the action of the carbonated waters upon these substances.

It will be obvious that these experiments may be greatly varied, care being always taken to produce such effects as we may conceive to take place in nature ; and that a great diversity of apparatus may be contrived for the purpose. We may even attempt to replace by other substances such parts of organic exuviæ as may be removed by the action of the solutions employed to percolate through mud, silt, or sands. With care we may, perhaps, obtain the complete removal of the carbonate of lime of shells by such means, such as has often been accomplished in natural processes, and succeed in introducing other substances, such as silica, into the resulting cavity. These and other experiments to illustrate natural processes by artificial means belong to what may be termed 'Experimental Geology,'—a branch of the science which has not hitherto received that general attention which its importance demands.

o. The principal mineral substance composing rocks which contain organic remains and are referred to a chemical origin, is limestone. In general, organic exuviæ are well preserved in calcareous deposits, which can be observed to take place in various situations where waters highly impregnated with carbonic acid lose that acid, and the carbonate of lime, previously held in solution by the aid of the carbonic acid, is thrown down upon any substance it may encounter. Organic substances are thus enveloped and preserved in calcareous matter, possessing various degrees of hardness and solidity, according to modifying circumstances. Petrifying springs, as they are termed, are known to every one. The sub-

stances placed beneath them are merely encrusted by the deposition of earthy matter, usually carbonate of lime, either by the loss of the substance from the water which held them in solution, or by the evaporation of the water altogether. An observer will readily perceive that such springs commonly collect together numerous plants, land-shells, bones and stones, which thus become cemented into a constantly increasing mass. He should direct his attention to those situations where ponds or small lakes are formed of carbonated waters, holding carbonate of lime in solution, and observe the mode in which organic remains often become enveloped by a calcareous deposit. The courses of running waters also will be found covered by calcareous deposits under the necessary conditions. When such deposits of calcareous matter, commonly termed Travertin or Travertino, are before him, an observer should endeavour to estimate their geological value, by noting the organic exuviæ they contain, their extent, depth, general character, and relative importance as portions of mineral matter forming a component part of the district.

p. Other substances, such as silica and sulphate of lime, are thrown down from mineral springs, as they are termed, in some situations: the mode in which they envelope animal and vegetable remains, their relative importance, and the conditions under which the resulting deposits are produced, should be carefully noted.

q. It is inferred that limestones are now forming extensively beneath the sea in many situations, and there envelope organic remains. Direct evidence on this subject cannot well be obtained, further than by

seeing if carbonate of lime be thrown down from sea-water, and envelope such exuviæ of animals and plants as it may encounter. Hitherto the evidence on this head has been extremely scanty; but marine shells and corals have been obtained which were cemented by compact calcareous matter, apparently the product of the present geological period; and stones and sand have been stated to have been taken from beneath sea-water, which were agglutinated by carbonate of lime, now forming in the same situations. If the saline contents of the sea be the same now that they were during the time when many calcareous deposits, full of marine shells, &c., were effected beneath the seas of former geological periods, we can see no reason, *à priori*, why similar deposits should not now be in progress. An observer should take into account the various conditions necessary to produce a calcareous deposit beneath the waters of the sea, containing the saline substances they now do, coupling it with the existence of creatures, the more solid remains of which may be subsequently entombed in the same situations.

r. Coral reefs have been considered by some to be extensive; that is, to cover a considerable submarine area with a broad sheet of calcareous matter, formed of the hard parts of saxigenous polypi, cementing shells and other hard parts of marine creatures. Others again consider, that they do not uninterruptedly cover extensive areas, but occur in isolated patches on the summits of submarine mountains, or in lines skirting coasts. No class of observers can possess such opportunities of studying the various conditions under which coral reefs

and banks exist as naval men, or of collecting data as to the depth at which certain species of coral descend in the water, the extent of such reefs, and the like. It would be desirable, if an observer be unable to distinguish the different species of corals himself, to grapple up specimens from different depths on the skirts of a coral reef, carefully put them away in some soft substance, so that the finer portions remain uninjured, with labels as to depth and situation whence they were taken, in order that they may be eventually submitted to the examination of experienced naturalists.

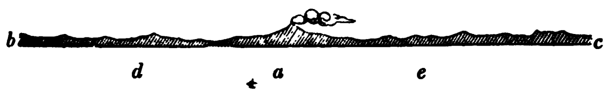
X. *Volcanos.*—From the striking character of volcanic phenomena, there are few persons who, being near a volcano at a time of eruption, have not to a certain extent become observers of such phenomena. In general, however, the observations made are of little value, with the exception of those recorded by a few scientific individuals, from the want of attention to those facts which more particularly deserve notice, and which lead to a right understanding of the cause of volcanic action.

a. An observer should in the first place attend to the situation of the volcano; not confining himself to the mere mountain itself, but taking in as much of the surrounding country as circumstances will permit. If the volcano be situated in a district composed of non-volcanic rocks, great attention should be paid to the position of the beds of such rocks, if they be stratified; noting whether or not they dip away from the volcano as a centre, or take other positions. Above all, it is necessary to sink the importance of the volcano itself, whatever may be its magnitude, in that of the district generally; by no

means allowing the splendour of the eruptions, and the personal danger frequently attending observations at such times, to interfere with a correct estimate of its relative size as a part of the earth's surface.

There is no better mode of reducing the undue importance an observer may attach to a single volcano, than by constructing a strictly proportional section of the country in which it may occur, the perpendicular heights and horizontal distances being on the same scale. If *a* (Fig. 57) represent the section of a volcano

Fig. 57.



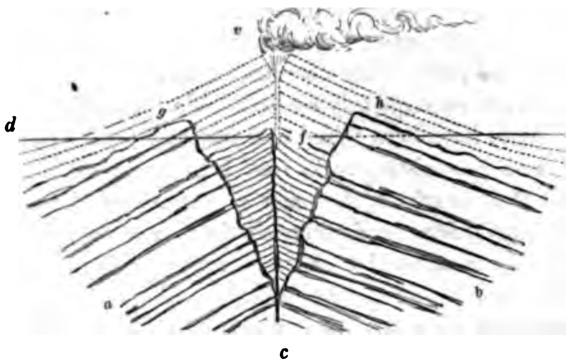
five thousand two hundred feet high; the line *b c*, a portion of country twenty-five miles in length; and *d e*, mountains about two thousand five hundred feet in height; it will be seen that, if we prolong the line, *b c*, about twenty-five miles on both sides, the volcano would soon lose that relative importance which has been purposely here given to it, by making it double the height of mountains on either side.

When instead of a single volcano an observer discovers a group of several, he should still keep in view their importance relatively to some given district, until finally he may, as in Iceland, find the whole country composed of little else than volcanic products. By these means he will not over-estimate the value of any given volcano or group of volcanos; neither will he, by thus classifying their relative importance, undervalue any volcanic district he may examine.

b. It has been much disputed of late whether, before a volcano came into activity in a district, the rocks composing the latter were or were not thrust upwards around the place where gaseous, liquid, and solid products were subsequently ejected. To the locality considered to have been raised and fractured by forces acting upon pre-existing rocks from beneath, more at one point than at others, the name of 'craters of elevation' have been given, to distinguish them from 'craters of eruption', considered to have been afterwards produced by the well-known ejection of ashes, cinders, and lava, which form a conical heap, with a funnel-shaped cavity towards the apex, kept open by the force with which the elastic vapours and gases escape upwards; thus driving ashes, cinders, and lava before them. Craters of eruption are again considered by other geologists to have been mistaken for craters of elevation; and it has been inferred that the observed phenomena may be explained by the shifting of volcanic vents, and the action of a volcano on the small scale in the centre of an area, which had been previously covered by the same volcano when in a greater state of activity, the matter necessary to complete the conical heap, which once covered the larger area, having been scattered during a great volcanic eruption.

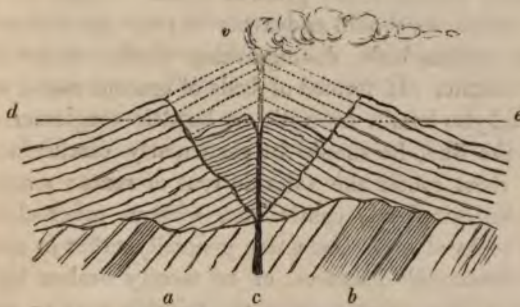
To illustrate the theory of craters of elevation, let *a b* (Fig. 58) represent a rock thrust upwards by a force, *c*, acting from beneath with such intensity as to fracture it. It is considered that the elastic vapours and gases, having now a free vent upwards, would pile up successive heaps of ashes, cinders, and lava in a conical form, partly represented by the dotted lines

Fig. 58.



beneath *v*, and that according to the amount of such accumulated volcanic products would be the appearance of the volcano taken as a whole at any given time. For the sake of better illustration, we have here supposed the first accumulations, from eruptions of cinders and the like, to take place beneath the sea, so that at some given period there may be a volcano, *f*, existing as an island, surrounded by an amphitheatre of land, *g h*, forming another island which is circular. It will be evident that, from successive volcanic accumulations, the cavity caused by the fracture of the fundamental rock, *a b*, will be filled, and that finally it may be entirely covered over and concealed by substances discharged from the volcano. The sketch above (Fig. 58) is only one of many modifications of contorted or broken strata with which cones of eruption may be connected, and to which the name of craters of elevation may be given. To illustrate simple craters of eruption, let *a b* (Fig. 59) be a mass of rocks, pierced at *c* by a crack or other

Fig. 59.



shaped rent, which has not upheaved the rocks, *a b*. Then if *d e* be the level of the sea, and ordinary volcanic eruptions take place upwards through *c*, they will gradually accumulate in successive conical layers until they attain any given altitude, such as *v*. It is considered that if all the mass represented by the dotted lines below *v* be now removed by some great volcanic explosion, and the volcano still continue in a state of minor eruption, we might obtain a volcanic island in the centre of an amphitheatre of land.

Before we direct the attention of the observer to particular facts, we should premise that the fractured and upheaved character of the fundamental rock, *a b* (Fig. 58), may be observed in many situations both on the large and small scale among rocks which are not volcanic, and that the occurrence of rocks so situated involves no geological improbability.*

c. The observer should endeavour to ascertain whether there is evidence of strata dipping from a central part outwards in any volcanic district he may examine,

* See "Researches in Theoretical Geology," p. 211.

be such district either great or small. Should he find such strata, he should endeavour to trace the continuity of the various beds, distinguishing whether or not they are volcanic. If formed of beds of igneous rocks, such as trachyte, basalt, trachytic or basaltic conglomerates, and the like, he should be particularly careful in tracing them round the volcanic vent or vents; since, if they be completely continuous, without other change than rocks of such characters generally suffer in moderate horizontal distances, or be merely broken by ravines in lines radiating from the volcanic vent or vents as a centre, the evidence would be in favour of a crater of elevation in such particular situation. If the rocks surrounding the volcanic district were not of an igneous character, but such as are commonly referred to an aqueous origin, and they were upturned towards the volcanic vent or vents as a centre, the evidence would also be in favour of a crater of elevation.

Should an observer find a series of beds dipping outwards around a volcanic district, simply composed of cinders, ashes, and the like, with here and there a body of hard rock, such as might readily be considered the section of a lava-current, the evidence would, as far as it goes, be in favour of a crater of eruption; though, as previously shown in Fig. 58, a crater of elevation may still be concealed beneath. There is, however, no reason, that we are aware of, why there should not be numerous simple craters of eruption which are not based on others of elevation, while at the same time there should be numerous volcanic cones, produced by successive eruptions, resting upon craters of elevation, many of which may not be visible. The accumulations

of ashes, cinders, and lava-currents, composing volcanic cones, are merely piles of substances thrown out by elastic vapours and gases at those points where such vapours and gases find vent. It will be evident that such vents may be as readily obtained at points along those great lines of fracture which exist on the earth's surface, as in situations where pre-existing beds of rocks have suffered great flexures and contortions, some of which have been somewhat hemispherical and fractured in their weakest parts, those which are highest and centrical. An observer should direct his attention to the magnitude of a crateriform cavity. If very large,—such, for instance, as that of Deception Island, New South Shetland,* which is five miles in diameter,—the probabilities are against such a crater being one of simple eruption, while relatively small craters may readily be referred to such an origin, in the absence of more direct information, often wanting in islands.

We can very readily conceive the existence both of a crater of elevation, in the centre of which there may be a crater of eruption, and of a crater of eruption without a trace of a crater of elevation, upon the same line of dislocation. Let *a b*, in the annexed sketch (Fig. 60),

Fig. 60.

* Journal of the Geographical Society.

represent a portion of a great dislocation or fracture of the earth's surface, such as are by no means rare in many countries. Let *a* be the point where the fracture may terminate in that direction, the crack becoming a flexure, which, denuded horizontally, produces the circular arrangement of rocks, *d a c*, or circus of elevation, as it is often termed when its dimensions are considerable. If volcanic vapours and gases, struggling to free themselves, find vent at this point, there would probably be a conical accumulation of ashes, cinders, and lava, surrounded by a circular escarpment of rocks, *d a c*, dipping outwards; and consequently there would be a crater of eruption in the centre of a pre-existing crater of elevation. Let *e* and *f* be two other points on the same line of dislocation where volcanic vapours and gases have forced themselves a passage, driving out ashes, cinders, and lava, and we should have two craters of simple eruption without any pre-existing crater of elevation, though we can readily conceive there would be a general tendency to bulge out pre-existing rocks in such situations. The observer will have no difficulty in conceiving many other irregularities and flexures on a great line of dislocation through which volcanic products might find vent; thus accumulating a heap or heaps of ashes, and the like, in the central portions of elevated rocks, arranged in the form of a crater, independently of the action of volcanic power itself, which being directed more to one point than another, might drive superincumbent rocks upwards, and form a large crateriform orifice, in the centre of which a conical pile of ashes, cinders, and lava may subsequently accumulate.

We would particularly advise the observer to study the probability of certain volcanos occurring in lines of dislocation, either straight or curved. The east and west line of volcanos extending across Mexico, and including the modern and suddenly developed volcano of Jorullo, has often been considered a great dislocation of the earth's surface, through which volcanic matter has been ejected at several points of least resistance.

d. The observer should direct his attention to the magnitude of a volcano, as compared with the violence of the eruptions from it. Volcanic eruptions are evidently of different degrees of intensity; but we can readily conceive that a given intensity, produced by any given conditions, may be modified and checked by alterations in those conditions; so that the maximum intensity of the eruptions from a volcano, in the early periods of its existence, may be greater than at later periods,—a given power of elastic vapours and gases having less resistance to overcome after a free vent is first formed, than when such vent is clogged up by a column of lava, cinders, and the like, supported by a large conical heap of cinders and ashes bound together by hard radiating lines of accumulated lava-currents. Consequently, all other things being equal, we should expect more subordinate lateral cones, and fewer eruptions from the central cone, in a volcanic vent which had been long in activity, than from the same vent at earlier periods of its existence. It will be evident, that the observer cannot well infer the relative antiquity of two volcanos, such as Etna and Vesuvius, because the one is larger than the other, and lateral cones exist on the one and not on the other, unless he could show that the

volcanic forces of the one are always equal to the forces of the other, and accumulate equal quantities of matter, producing equal antagonist action, in equal times.

e. Observations on the chemical composition of the various vapours and gases ejected during a volcanic eruption, as well as of those thrown out from crevices and fissures in the crater and sides of the same volcano in a state of minor activity, or of repose, as it is frequently termed, are highly important, because they lead us to a knowledge of the cause of volcanic action itself. It is at present a somewhat prevalent theory, that volcanic action is caused by the percolation of sea, or of other water containing the same salts in solution as those found in the sea, to certain metallic bases of the earths and alkalies. To try the value of this, or of any other theory founded on the percolation of water to volcanic foci, it will be evident that examinations of the vapours and gases evolved from volcanos at various distances from the sea, or other large bodies of superficial water, are important. The observer, if a chemist, will readily proceed to the examination in a manner to ensure success. If he be not a chemist, he may still collect the vapours and gases for examination, by attending to the following instructions:—

He should select glass-bottles to which stoppers have been accurately fitted by grinding; and he may himself grind stoppers into the bottles, or improve their fit by means of fine emery moistened with water. The bottles should then be filled with spring-water (or distilled water if at hand), be emptied as close as possible to the spot whence the gaseous matter is issuing, and then closed before removal from the spot. The stopper

should be first smeared with a thin layer of spermaceti ointment or candle-grease, and its line of junction with the neck of the bottle be covered with cement made of wax melted with half its weight of resin. The stopper should then be tied down tightly with twine. Bottles capable of holding two, three, or four ounces of water suffice for most purposes; but larger ones, if at hand, should be preferred. If bottles with glass-stoppers are not to be had, common wine-bottles and corks may be substituted. The cork should be first softened by percussion between two flat pieces of stone or wood; and when tightly introduced, any portion of the cork projecting above the mouth of the bottle should be cut off, and its surface covered with wax-cement or sealing-wax melted upon it.

f. If there be not too much danger attending the approach to the craters of volcanos at periods of active eruptions, the gases and vapours should be collected at different times during such eruptions, in order to ascertain if any change take place in their character or relative proportions at such times. It is generally considered that carbonic acid gas, when evolved, is thrown out towards the close of some considerable eruption.

g. When practicable, the various sublimations observed in fissures and other situations in volcanic craters should be obtained with care; those liable to deliquesce, or suffer change by the action of the atmosphere upon them, being preserved in bottles with ground glass stoppers and well sealed, so that when subsequently examined they may be as nearly as possible in the state in which they were obtained at the volcano. A comparison of such products obtained from various volcanos

differently situated would assist in advancing our knowledge towards a true theory of volcanic action.

h. With regard to the liquid melted rock, or lava, ejected from a volcano, its chemical and mineralogical composition will necessarily depend upon a variety of circumstances which an observer can have little opportunity of knowing. Its principal character will be that of the mass whence the body of lava is derived, whether such mass be composed of the oxides of certain earths and alkalies then first formed by the percolation of water to their metallic bases, or of liquid heated matter produced by other causes. The depths whence lava is generally derived is probably far beneath the surface of rock exposed to our examinations in the localities where it is ejected. An observer may, however, endeavour to see if there may be any connexion between the chemical composition of the lavas thrown out of any given volcano, and that of the rocks forming the district generally. Portions of rock that are evidently parts of those found in the surrounding districts are ejected from some volcanos. Thus pieces of limestone have been ejected from Vesuvius of the same kind as those forming the surrounding calcareous mountains, so that the volcanic vent probably traverses a subterranean continuation of the rocks composing these mountains, and portions of them are occasionally there broken off. If these had not been suddenly thrown out, they would probably have been melted in the common mass of lava, the carbonic acid being driven off, and the lime combined with silica, rendering the whole mass more fusible from the presence of a larger proportion of silicate of lime. Many argillaceous slates, and rocks of the mine-

ralogical character of those termed grauwacke, may readily be converted into pumice by a little management in our furnaces ; so that we can conceive the pumice of the ancient volcanic district of the Rhine to have been portions of the grauwacke of the neighbouring country converted by heat into that substance. It must not, however, be supposed that all pumice is thus derived.

i. It would be desirable for an observer to detach specimens of a fair general character from lava-currents of different ages ejected from the same volcano, in order to see if there be any marked chemical difference in their respective compositions, such as might lead to the opinion that the conditions under which the lava has been produced have varied during the time which has elapsed since the volcano first ejected liquid melted rock.

k. It would also be desirable to observe, among the more ancient volcanic conglomerates, if any such be exposed around a volcano whence portions of non-volcanic rocks are ejected, whether similar portions of rocks be more numerous in them than would probably be the case in the conglomerates now produced around the same volcano ; because, if found to be so, there has been a change of conditions under which such fragments of non-volcanic rocks have been thrown out. We can readily conceive, that when volcanic substances are first discharged through a vent situated among non-volcanic rocks, there would be a greater tendency to drive off and eject portions of the latter than when the passage had in some measure been cleared of points of resistance. If the converse be observed,—that is, if portions

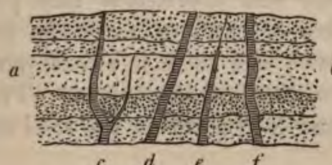
of non-volcanic rocks be not discovered in the older conglomerates of a volcano, while such fragments be now ejected from its crater,—some change of conditions must still have been effected, though produced by other causes than that noticed above as probable.

l. The extent to which fragments of rock, portions of liquid lava, cinders, and ashes may be scattered around a volcano in a state of violent eruption, should be noted, in order that we may duly appreciate the character of the resulting deposit, whether it be effected on dry land, or beneath fresh-water lakes or the sea. The distance to which the lighter ashes may be carried by atmospheric currents is well known to be considerable. It would be desirable to ascertain the chemical composition of such finely comminuted volcanic matter, in order to appreciate any change that may be subsequently produced in or by it, whether it fall upon land or water.

m. The vapours and gases evolved from Solfataras, as they are termed from the Solfatara near Naples, should be examined with care; and the chemical products resulting from their action upon the lavas, cinders, and ashes they may encounter, should be noted. Solfataras may to a certain extent be considered as volcanos in a semi-active state; the relatively small amount of vapours and gases produced readily finding vent, as it were, through a safety-valve, no explosions of highly compressed elastic matter take place, and consequently no piles of solid substances, driven upwards by such explosions, are accumulated at the mouth of the vent in the form of a cone with a funnel-shaped cavity at its apex and down its axis.

n. If the observer study the internal portions of volcanic cones, exposed by various causes to examination, he will frequently find lines of solid rock cutting beds composed of cinders, ashes, and the like, as in the annexed sketch (Fig. 61), in which *a b* represents a

Fig. 61.



horizontal section of conical or other coatings of cinders and the like, traversed by the lines of solid rock, *c d e f*. These lines of solid rock are termed volcanic dykes, and are the result of fissures in the beds *a b*, (caused by the heaves and throws of the volcano during times of activity,) filled by liquid lava, which has either risen or been ejected into them. An observer should examine the mineralogical composition of these lava-dykes, noting how far the same elementary substances may have combined, or been arranged, differently in the matter of the dykes and in that of the common lava-currents of the volcano, in consequence of the different conditions to which they have been respectively subjected. He should also note to what extent, if any, the particles of the ash or cinder beds near the dykes may have been compelled to arrange themselves, when exposed to the heat of the lava filling the fissures, differently from the relative positions they previously occupied, and which relative positions similar particles still occupy in other and con-

tinuous portions of the same beds. The alterations, as they are termed, thus caused, are sometimes highly deserving of attention.

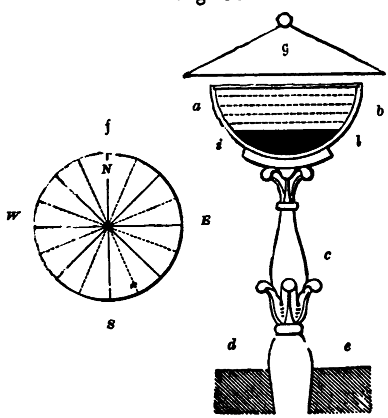
XI. *Earthquakes.*—The geological importance of earthquakes consists in the elevation and depression of land that may be produced by them, particularly when such elevations and depressions take place on the shores of lakes or seas, or across the lines of river-drainage on land, and there is a consequent alteration in the physical features of districts. They also produce cracks and dislocations in the solid surface of the earth.

a. The magnitude of the area agitated by any given earthquake is an object of considerable importance, inasmuch as it is one of the chief elements to be taken into consideration when we search into the cause of earthquakes. It will be obvious that no single person can, from his own observations, estimate the area agitated by an earthquake, though much may be accomplished by the combined observations of many. It is therefore important that a similar series of notes should be taken by various observers, whenever earthquakes occur under circumstances which may enable them to do so.

b. Earthquakes are generally stated to be felt in lines, sometimes in one direction, sometimes in another. It is consequently desirable to learn whether such lines form portions of great curves, and may therefore appear straight for comparatively short distances, or are really straight, as regards any given direction on the earth's surface, for long distances. This knowledge also can only be obtained by the combined observations of several persons. Mr. Babbage has suggested a simple, and,

as it appears to us, certain means, of registering the direction taken by an earthquake. It consists in partly filling some convenient glass-vessel with treacle or other viscous fluid, which, when lateral motion is communicated to it from the earth, is marked in two opposite directions by the wave produced in the treacle or other viscous fluid. A line drawn across the two highest and opposite points marked by this wave would give the direction of the shock by which it was produced.* If instruments founded on this principle were constructed alike in every respect, we might not only obtain the

Fig. 62.



direction of earthquakes, but some information respecting their intensity at different places. Let *a b* in the annexed sketch (Fig. 62) be a hemispherical basin of a

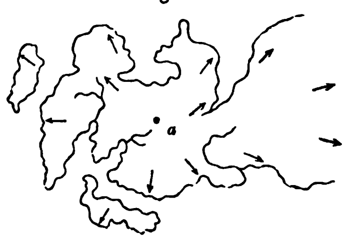
* "Economy of Manufacturers," 2nd edit. p. 58.

given size, formed of glazed earthenware or glass, as may be considered most convenient, filled up to the height *i l* with treacle or any other substance considered most likely to attain the end desired. Let equidistant horizontal lines be marked in the interior of the basin from the treacle to the rim ; and let the basin be tightly fixed upon a perpendicular pedestal, *c*, driven firmly into the ground, *d e*, in some sheltered court or garden, away from any vibrations produced by accidental causes in a dwelling-house, and from the fall of any building upon it during an earthquake. To keep the interior of the basin clean and free from insects, a circular glass disc should cover its rim exactly ; and in order to render this disc still further useful, the various points, North, South, &c., should be correctly marked in lines, as at *f*, upon it, so that the lines of the disc being arranged to correspond with the *true*, not the compass, North and South, the direction of the wave produced by the shock of an earthquake may be at once seen, without first disturbing the basin. In situations where sufficient protection from the weather is not afforded to the instrument, a conical covering, *g*, should be supplied. Such instruments would essentially cost but little, and might be extensively employed in countries agitated by earthquakes. By their means we should not only obtain the direction of shocks, but some information as to their intensity, as far at least as a greater or less waving motion of the earth was produced, by the relative height to which the treacle or other viscous fluid might rise in the basin.

c. Supposing the above or any other convenient instruments constructed for similar purposes were exten-

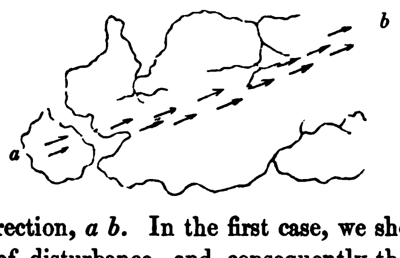
sively distributed, we might eventually learn whether, as in the annexed sketch (Fig. 63), supposed to represent some given portion of country, there was a point,

Fig. 63.



a, from which the various shocks seemed to radiate, decreasing in intensity as they receded from *a* as a centre; or whether, as in Fig. 64, they followed a long marked

Fig. 64.



line of direction, *a b*. In the first case, we should have a centre of disturbance, and consequently the cause of the earthquake produced vibrations around it. In the second, we do not know that any portion of the superficies of the globe has been so acted on as to produce vibrations from a central point of some part of such superficies outwards. The vibration may merely have run along a line of some great previous fracture of the earth's crust, upon which a force acting upwards, from a

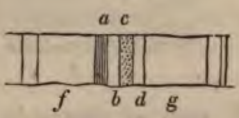
situation deeply seated beneath the surface, would more readily produce vibrations, from the comparatively less resistance of parts in that or similar lines, than in portions of the earth's surface not so fractured. As it is no part of our object to press particular theories upon the attention of the observer, we must refer to geological works for those which account for earthquakes, leaving him to adopt such as may appear the most probable. He will perhaps come to the conclusion, that the vibrations of the earth's surface, commonly termed earthquakes, may be due to more than one cause. If so, he will expect a difference in the effects produced, and consequently look to detailed observations, made with the best means in our power, for those facts which, being subsequently classified and duly weighed, may ultimately lead to the knowledge required.

d. Let earthquakes be caused by what they may, the vibrations produced by them will be modified and disturbed by the nature of the substances through which they pass. An observer, therefore, should direct his attention to the compactness or other characters of rocks in districts agitated by earthquakes. A force acting with a given intensity may produce very different vibrations in rocks of different structures, and the force may in some cases be just sufficient to cause vibrations in one rock and not in another, so that an earthquake may be felt in the line of one rock and not in another. As, however, the effects resulting from this cause would greatly depend upon the relative position of the rocks, due care should be paid by the observer to this circumstance. Rocks also piled horizontally upon each other might transmit vibrations through them more readily in

that position, from the action of a given force, than when the same rocks were in a perpendicular position and acted on by the same force; because, in the latter case, the resistance would probably be greater than in the former. Let *a*, *b*, *c*, *d* (Fig. 65) be four rocks lying

Fig. 65.

Fig. 66.



horizontally upon each other, and acted on laterally by a force at *e*, then there would be less resistance to vibrations than when the same rocks were placed vertically and bound in by other masses of rock, *f*, *g* (Fig. 66), and the same force acted laterally upon them in the direction of the eye of the reader.

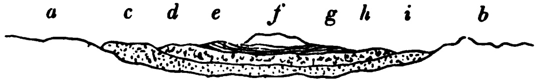
An observer should endeavour to trace whether there be any coincidence between the general direction of mountain ranges and that of earthquakes, as also whether there may be any such coincidence between prevalent shocks and the direction of strata generally in a district, such strata not having been forced up into mountain chains. He should, however, recollect that the general direction of a mass of rocks, composing a portion of the earth's surface, may be masked by more modern accumulations, and therefore he should endeavour to ascertain if there be any probability of such older rocks running in lines beneath the more modern deposits. For if lines of direction, in stratified rocks, could influence the line of shocks in an earthquake, and the cause of the earthquake act from beneath, such influence

would be first exercised by the direction of the lowest rocks, and tend to modify the vibrations produced in those above them. Let *a b* (Fig. 67) be a stratified

Fig. 67.

rock, such as grauwacke for instance, and let it have an east and west direction, and contain in a trough-shaped cavity other rocks, *c i*, *d h*, *e g*, and *f*, in such a manner that a vertical section would show them to occur as represented in Fig. 68, where the same letters

Fig. 68.



mark the same rocks as in the horizontal plan, Fig. 67. And further, let the outcrop, or rising of strata to the surface, be such, that the lines of the outcrop and directions of the beds of the rocks *c i*, *d h*, *e g*, and *f*, be N.N.E. and S.S.W. nearly. Then if shocks of an earthquake be found to take an east and west direction, at any situation upon the rocks *c i*, *d h*, *e g*, and *f*, it should not be too hastily concluded that they are not influenced by the direction of strata beneath, because the superficial rocks have a direction N.N.E. and S.S.W.; since, in this case, the shocks in question, if influenced by the direction of the lower rocks, would

coincide with the direction of the strata of the rocks *a b*, because they would be first acted upon.

e. If after earthquakes there be reason to consider that land has either been raised or depressed by the shock or shocks, great care should be taken to ascertain correctly the amount of such rise or depression. For the most part, the general sea-level is that which is not only the most convenient, but most certain, for purposes of comparison. To produce any great change in it by any cause which can alter its level, there must be such an amount of solid matter moved up or down beneath the ocean, that the term earthquake, as usually employed, could not apply to such an exercise of subterranean force, be the cause of the force what it may.

An observer should most carefully measure any rise or depression of a coast, produced by an earthquake, with the mean surface-level of the sea before and after the event; the exact difference between the two being the true measure of the rise or depression, as the case may be. It is probable that by a due attention to exactitude in this respect, proper allowances being made for the variable height of tides where such occur, and for the influence of winds in locally raising or depressing the sea-level at a time of observation, the rise or depression of land from earthquakes would sometimes be found greater and sometimes less than the measures often given.

It is necessarily a difficult process to trace any such rise or depression inland, unless the country be one in which the height of a variety of points, above the sea-level, has been ascertained with exactitude, when any change in their relative heights would afford that of the

rise or depression caused by an earthquake. There is scarcely a country the heights of which are measured with such precision as to afford exact data for this purpose; though there are, no doubt, some countries of which certain points seem to have been most accurately ascertained. If, however, the general drainage of a country rise inland, as is commonly the case, observations on the velocity of rivers would be found valuable, when their previous velocities are known, as sometimes happens, to a certain extent, where mill-dams or other obstructions cross a river, and, consequently, where any change producing a greater or less slope in the river-bed is soon detected. It is extremely desirable to obtain precise information upon this subject; for, hitherto, calculations intended to give an idea of the cubic contents of masses of land, either raised or depressed by any given earthquake, have not rested on such data as could be desired. They may readily have been either greater or less than those calculated.

f. Although it would generally be exceedingly difficult to estimate the depth to which any given line of coast may have been depressed beneath the sea-level by a succession of earthquakes, unless sufficient historical documents exist to do so, the height to which it may have been elevated by such means may be inferred, if an observer discover a series of beaches elevated above each other on a coast known to have been raised by any earthquake, the last beach having been clearly elevated by such means. Due care must, however, be taken to estimate the value of other causes which may have produced the effects observed.

g. In cases where the bottom of the sea is considered to have been raised by an earthquake, and a neighbouring volcano has been in a state of activity at the time, an observer should endeavour to ascertain if any considerable amount of ashes and cinders has fallen into the sea in the situation where the bottom has been supposed to have been thus elevated. He should also direct his attention to the sea-level on the adjoining coast. If there be no relative change as regards the level of the sea-line on the coast, and there has been a considerable fall of cinders and ashes in the locality considered to have been raised, the supposed rise caused by an earthquake is probably deceptive. Even on coasts where there has been no fall of volcanic substances, proper allowance should be made for the addition to beaches in favourable situations, produced by the great breakers generally discharged with great fury on coasts during earthquakes. These accumulate a great body of detritus in such situations, upon the same principle that the breakers, during a heavy gale on shore, accumulate greater beaches in front of low land than in more moderate weather. Proper attention should also be paid to the probable accumulation of live molluscs, corals, &c., by such breakers, the result of waves which tear up the sands and mud, and break off portions of corals, sea-weeds, &c., and discharge them on shore, on the same principle that minor breakers and waves near coasts do so during gales of wind. We are desirous to place an observer on his guard where circumstances may be equivocal, and that, under such circumstances, the mere addition of height to a given beach, or a long line

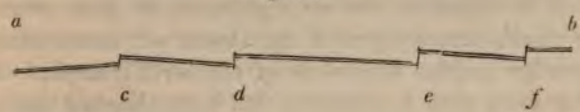
of accumulated live molluscs, &c., may not be considered good evidence, in the absence of better, of a rise of land from an earthquake in that particular situation.

h. It can scarcely be expected that during those earthquakes where rents and fissures are produced in the ground, an observer can calmly direct his attention, amid the danger which surrounds him, to the gases or vapours which may escape from such rents and fissures. He may, however, be conscious of any particular odours that may escape from the fissures, as also of any appearance of flame. The latter is sometimes stated to have been witnessed; and if the appearance has not been deceptive, it is desirable to possess such data respecting it as may lead towards a knowledge of its cause. The exact amount of dislocation of rocks caused by an earthquake should be carefully noted; and the number of feet which one side of a fissure may rise or fall above or beneath that of the other should be ascertained, observing whether such relative change in the level of the rocks on either side be produced by a rise or fall generally of the land around. It is exceedingly desirable that all such changes be measured, and the exact measures recorded; and that they be not merely described as 'enormous!' 'stupendous!' and the like, when, perhaps, a change of level produced in the two sides of a fissure, and thus characterised, may not be more than from four to ten feet. When noticing such terms, we cannot but express a hope that they may be omitted in geological descriptions, since they convey no definite ideas of height, depth, or distance, and lead only to vague, and, for the most part, exaggerated, notions of things which can readily be measured. We once mea-

sured, and reached the bottom of, a 'fathomless abyss,' with a line of about ninety feet! and have seen 'enormous dislocations,' so trifling that they were difficult to discover.

i. The direction of any fissures or ridges of raised ground, caused by earthquakes, should be carefully observed, and their length and breadth as accurately noted as possible. Whether they run in lines parallel to each other, or radiate from some central point, should also be ascertained; and whether, if parallel, the dislocations have been effected in the manner represented in the annexed imaginary cross section (Fig. 69), where the

Fig. 69.



surface of a nearly level tract of land, *a*, *b*, has been so dislocated in parallel lines, *c*, *d*, *e*, *f*, that three ridges and depressions have been produced. All changes and their probable consequences in the physical features of a country, either ridged, furrowed, or otherwise altered by the effects of earthquakes, should be noted; and when numbers can be used to convey definite ideas of such changes, they should be employed. Thus, instead of informing us that the course of a river has been arrested by an earthquake, that a lake has been the consequence, and that this lake, when it 'bursts,' would excavate valleys, &c. we should be informed whether a river had been stopped by the fall of loose rocks and

other substances in a ravine or other situation where such an effect could be produced, or whether a ridge caused by an earthquake had dammed back the waters of a river; in either case, giving us the height, breadth, and composition of the dam. When accumulations of water are produced in consequence of rivers arrested in their progress, we should have some definite description of their length, breadth, and depth, and consequently of the body of water they may contain; so that, when it is inferred that valleys may be excavated by the 'bursting,' as it is termed, of such lakes, we may be enabled to judge of the manner in which the waters may obtain a passage through the dams, and of the probable effects which may be thus produced.

XII. *Gradual rise or depression of large tracts of land, unaccompanied by shocks of earthquakes or other sudden movements of the earth's surface.*— For more than a century it has been observed that a change was slowly taking place as regards the relative position of sea and land in parts of the shores of Sweden bathed by the Baltic; and Von Buch long since asserted that the surface of Sweden was gradually rising from Frederickshall to Abo, and that such rise probably extended into Russia. Of late this important circumstance has received that further attention that it deserved, and it has been asserted that the rise of land was unequal, taking place more on the north than on the south; so that the rise is at the rate of four feet in a century in the northern part of the Gulf of Bothnia, and not observable in the islands of Œland and Gottland.

a. When such an elevation of land is suspected, ob-

servations to ascertain the fact should be conducted with great care, and with due regard to those local circumstances which may affect them. It is evident that, in the first place, proper marks should be made on cliffs or other sufficiently stationary objects, showing the height of the sea-level as regards the coast at some given time. To fix upon such level is no inconsiderable difficulty, in tidal seas especially. Even considering that tides, taken by themselves, so occur that a mean might be obtained of their height at any given place, it scarcely happens that they are not modified in their exact height by the pressure of the atmosphere at the time, and by the state of the winds generally in a considerable area around the given locality. After the prevalence of a strong wind on shore for some time, it frequently happens that high water is kept up beyond the proper time in harbours, and the level of the tide is forced up, even to as much as two or three feet, beyond what it would have been if there had been no strong prevailing wind on shore. When a strong off-shore wind continues for some time, the reverse happens; and what is thus true of high water is also true of low water. These effects are again modified by the state of the tides at the time; much depending upon their being springs or neaps, as they are technically termed.

b. In tideless seas, such as the Baltic and Mediterranean are commonly termed, though they cannot obviously be strictly so, similar precautions as regards the pressure of the atmosphere and the state of the winds during an observation are necessary, otherwise very serious errors may be committed. It is well known that the Baltic is kept up at least two feet by a strong and con-

tinued north-west wind; the Caspian sea is higher by several feet at either end according to the prevalence of a strong north or south wind; and it is equally well known that the height of the sea in the ports of the Mediterranean is greatly influenced by the state of the winds for the time.

c. In noticing the foregoing sources of error, we by no means intend to throw doubt on the probable slow rise and depression of land now taking place in various parts of the earth's surface: on the contrary, we believe that they do occur more generally than has been hitherto supposed, and we have repeatedly stated our opinion that such gradual rises and depressions of the solid part of the earth's surface are necessary to explain many geological phenomena observable in the fossiliferous rocks, as well ancient as modern.* We merely desire to call attention to certain necessary precautions, when a given locality or line of coast is under examination, so that, in the first place, there may be a certainty of the locality or of the coast rising or sinking, as the case may be; and in the second, that, if the one or the other be matter of fact, there may be no error in the *amount* of elevation or depression stated to take or to have taken place in a given time.

XIII. *Temperature of the Earth.*—We include under this head observations on the temperature of rocks, &c. in mines, and on the temperature of seas, lakes, Artesian wells, and springs. We shall abstain from pressing particular theories upon the attention of the observer, leaving him to adopt such as may

* See "Geological Manual," and "Researches in Theoretical Geology."

appear to accord best with the phenomena he may notice.

a. In observations of this kind it is essential that the thermometers employed should be of the best possible construction,—not graduated in the common way by merely noting the freezing and boiling points of water at a given height of the barometer, and then marking a certain number of equal parts between these points, according to the scale adopted; but by carefully verifying the graduation at numerous points with standard thermometers, constructed with every requisite care. In delicate observations of this kind regard should be paid to the age of the thermometer itself, since it has been found that in mercurial thermometers the freezing point slowly rises after graduation; and as the principal effect is produced soon after the tube is sealed, it has been recommended that some months should elapse between the sealing and graduation of a thermometer.

b. The numerous sources of error which may influence observations on the temperature of the air or water in mines or collieries, though they may be conducted by very skilful and experienced persons in such a manner as to ensure success, when the sources of error are duly considered, are such that more direct observations should be preferred whenever practicable. Great care should obviously be taken to avoid any source of error either in the instruments or other means employed. The following was the process adopted by M. Cordier, who has given great attention to this subject, when he obtained the temperature of the rock itself in some coal-mines of France:—The thermometer was loosely rolled in seven turns of silk paper, closed at bottom, and tied by a string

a little beneath the other extremity of the instrument, so that so much of the tube might be withdrawn as might be necessary for an observation of the scale, without fearing the contact of the air; the whole contained in a tin case. This was introduced into a hole from twenty-four to twenty-six inches in depth, and one inch and a half in diameter, inclined at an angle of 10° or 15°; so that the air once entered into the holes could not be renewed, because it became cooler and consequently heavier than that of the galleries. The thermometer was kept as nearly as possible at the temperature of the rock, by plunging it among pieces of rock or coal freshly broken off, and by holding it a few instants at the mouth of the hole, into which it was afterwards shut, a strong stopper of paper closing the aperture. The thermometer generally remained in this hole about an hour.*

Observations have also been made by drilling a hole, a yard or other convenient measure in depth, in the rock of a mine, and observing the temperature during any given period, such as a year or more. It may be stated, that from the observations hitherto made on the temperature of the rocks in mines, and, even with every allowance for error, on that of the air or water of such situations, there is an increase of temperature downwards from that depth where changes of temperature are not produced by the climate to which the actual surface is exposed. It is scarcely necessary to state, that observations should be made on rocks at various depths, and in situations as little as possible under the

* Essai sur la Température de la Terre: Mém. de l'Acad. tom. vii.

influence of heat occasioned by the presence of miners with their lamps or candles, by the blasting of gunpowder, or by a mixture of iron pyrites, water, and shale, where such occur.

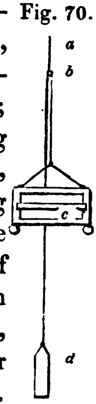
c. Observations on the temperature of the sea at different depths may for the most part be made with those thermometers commonly termed register, in which the graduated tubes are placed horizontally, a mercurial thermometer pushing forward an index to the greatest heat to which the instrument has been exposed in the sea, while an alcohol thermometer draws back on another index to the greatest degree of cold to which it has been subjected; so that the observer learns the extremes of temperature to which the whole instrument has been exposed after it quits the surface. Observations, therefore, at considerable depths might be considered uncertain with such an instrument, if care be not taken to obtain the temperatures of the sea at various intermediate depths, since changes might have happened at such various depths, and the register thermometer merely marks the extremes of temperature to which it has been subjected. There are various other instruments, a knowledge of which an observer may readily obtain at the best philosophical instrument makers, contrived for the purpose not only of taking the temperature of the sea at various depths, but also of obtaining water at the same depths.

Of whatever kind the instrument employed may be, in all those in which the temperature of the water is not taken after a portion of the latter has been withdrawn from any given depth, but in which a thermometer is made to descend in the sea, it is necessary that the

materials of the instrument employed, viewed as a whole, should be such as readily to take the temperature of the depth to which it may be plunged, and that the thermometer should have some contrivance for registering the temperature; since the same materials which speedily take the temperature at various depths, as readily permit the thermometer to be affected by changes in the temperature of the water when drawn upwards to the surface.

In cases where an observation may be rendered uncertain by a shock of the instrument employed upon the bottom of the sea, when such bottom may be touched by the length of line to be run out, it is desirable to have the sounding lead so arranged, with respect to the instrument for obtaining the temperature, that when the former touches the ground, the line may be held firm and the lead raised above the bottom, so that the jerks, which might be caused by the pitching or rolling of the ship or boat above, and derange any index for registering temperatures, may be as much as possible avoided. We have often arranged the line, instrument, and sounding lead upon the principle represented in the annexed woodcut (Fig. 70), and have found it answer the purpose intended:—*a* is a line leading up to the boat or ship; *b*, a point where another line, *e*, supporting the instrument for ascertaining temperatures, *c*, is attached to it; the main line, *a*, being continued down to the sounding lead, *d*. The line *e* supporting the instrument may be of any convenient length, and that of the main line, from the point *b* to the sounding lead *d*, either ten, one hundred, or any other number of feet, as an observer may think proper.

Fig. 70.



It will be obvious, that when the lead *d* touches the bottom, and is felt by the person sounding, the line should be held firm, so that the instrument does not strike against the ground. If the bottom of the lead *d* be armed, as it is termed, in the usual manner, the temperature of a given depth, the actual depth of the sea at a given place, and the kind of bottom, are all ascertained at the same time.

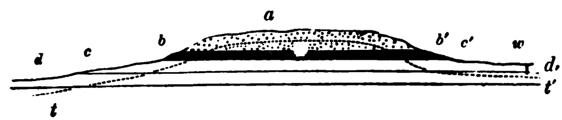
d. Observations on the temperature of the sea are to a great extent simplified by the fact, that sea-water attains its greatest density at about the temperature that it becomes ice; so that in situations such as the tropics, where the surface temperature never approaches that of the freezing point of water, there would be a constant decrease of temperature downwards, and the lowest temperature would not be so low as the freezing point of sea-water. In the colder regions of the globe, where the surface-water is so exposed to temperatures producing densities which may either cause it to keep its place, or descend within a small range of the thermometer, variations of temperature will occur which it will require very great care on the part of the observer to ascertain.

e. The temperature of lakes of fresh water may be obtained with the same instruments and in the same manner as that of the sea. Such observations are, however, rendered still more simple by the knowledge of the fact, that fresh water attains its greatest density at a temperature of between 39° and 40° of Fahrenheit's scale, and consequently that all fresh water of a greater or less temperature will float above water of that temperature. The observer should direct his attention to

of Artesian wells, which discharge a large volume of water in a given time, should be found to rise slightly, which we might expect if thermal waters gradually acquired a more free passage to the surface than they at first possessed. If thermal waters rose to a surface considerably beneath that of the soil in any given district, and there spread out in tabular sheets between strata, it will be evident that they would eventually take the temperature of the strata between which they occur; and, therefore, if they are subsequently and suddenly conveyed to the surface by artificial means, they will afford the temperature of rocks at known depths.

g. It having been considered that common springs in the tropics possess temperatures lower than those of the climates in the same localities, and that those of the cold regions of the globe are, on the contrary, higher than the mean of the climates in such situations, it becomes important to ascertain the temperature of common springs with precision, in order to see how far the facts may be general. If they be general, there will be some modifying influence distributing a more uniform heat over a certain depth beneath the earth's surface, than would appear probable from the mere effect of solar influence. As very great exactitude is necessary in observations of this kind, every care should be taken duly to estimate any causes of error which may present themselves.

In the first place, the observer should, if possible, ascertain the condition under which the springs exist. Some modification of the conditions represented in the annexed vertical section (Fig. 72) is not uncommon. Let *a* be a porous rock—a slightly aggregated sandstone,



for instance—resting on a bed, *b b'*, nearly impervious to water, such as clay; then rain-water falling upon the top of the hill is in a great measure absorbed by the porous rock *a*, but its progress downwards being checked by the clay, or other nearly impervious bed, *b b'*, it comes filtering out in the shape of springs on the side of the hill at the level *b b'*. Let us, for further illustration, suppose another porous rock, *c c'*, to occur beneath *b b'*, and that in its turn it is supported by a bed of rock nearly impervious to water, *d d'*; then the rain falling upon the rock *c c'*, will be first absorbed and afterwards filter out in springs on the side of the hill at *c*, but not at *c'*, because the nearly impervious bed *d d'* is not exposed on the surface in that direction. But if a well, *w*, be sunk on that side of the hill, the same water will evidently be obtained as at the junction of the beds *c* and *d* on the other side of the hill. The water in these cases is first at the temperature that it takes in the atmosphere; but percolating through the rocks which absorb it, it becomes of their temperature. Now, if these rocks vary in temperature according to their depth beneath the surface of land, there would be a line of uniform temperature, represented by the dotted line *t t'*, parallel to, and beneath, the actual surface, *d c b a b' c' w*; and consequently, if water percolates slowly to the surface in the shape of springs, it would probably take the temperature of the rocks, all other things being equal, between the line *t t'* and such surface; whereas, if

it rose more rapidly, it might carry with it the temperature of lower depths, in proportion to the volume of water discharged and the velocity with which it was so discharged. Hence the quantity of water delivered by a spring in a given time, and the rapidity with which it rises, require to be duly estimated.

Other springs again are evidently not modifications of the above conditions. They sometimes rise from dis-

Fig. 73.

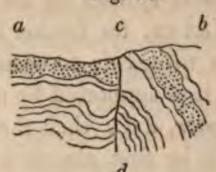
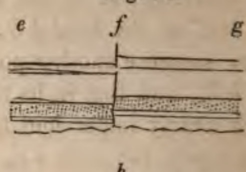


Fig. 74.



locations of rocks, commonly termed *faults;* such are represented in the sections above (Figs. 73, 74), where *f h* represents a dislocation of nearly horizontal rocks; *c d*, another dislocation of disturbed rocks. In such cases we cannot be certain that the waters, rising through the fissures *c d* and *f h*, to the respective surfaces *a b* and *e g*, may not be derived from great depths, and bring the temperatures of such depths with them to the surface, modified by any change they may suffer in rising upwards, which depends, as we have before seen, upon the rapidity with which this can be accomplished, the volume of water being duly considered. This caution is the more necessary, since warm or thermal springs commonly appear to rise through fissures, and would in such cases necessarily be modified in temperature according to obvious circumstances.

Springs in limestone countries frequently rush out with great force: they may in some instances be termed small rivers. This arises from the cavernous character of such districts, and the generally ready manner in which rains are swallowed up in cavities communicating with the surface; often also from the highly tilted character of the beds in such districts. In the great tract of country formed of compact white limestone in Jamaica, this fact is remarkably exhibited. Notwithstanding the heavy fall of tropical rains in that district, nearly the whole is immediately swallowed up by innumerable holes and caverns, which join in subterranean passages; so that a spring, properly so called, can scarcely be seen for considerable distances, while here and there a small river rushes to-day from amid the rocks. To judge of the temperature of the earth, at those relatively small depths where climate ceases to have an influence, by that of such waters, will depend upon the time the latter may have remained beneath among the rocks, so that they should acquire their temperature.

The observer should therefore weigh well the conditions under which the springs he may examine come to the surface, and, when he notes their temperatures, should also note so many of such conditions as he can ascertain. In this manner we should ultimately obtain several series of classified facts, and consequently be not only enabled to judge of the relative value of each series, but also of the whole viewed generally. It is necessary to caution an observer against one circumstance which, from experience, we have found to require much attention. In taking the temperature of a spring, he should

clear away the ground so as to get as near as possible to the spot where the water actually rises from among the rocks. Without this precaution, an error of two or three degrees may readily be committed. In thermal springs it is especially necessary, particularly when the volume of water discharged is not considerable. The thermometer should also be introduced into the aperture whence the spring rises: and if the observer be accustomed to handle delicate instruments, he will find one of those thermometers in which the bulb and a portion of tube project beyond the graduated scale most useful, as well as most likely to afford accuracy.

XIV. *Gaseous Exhalations.* — Gaseous exhalations are observed in many parts of the world in situations which cannot be strictly termed volcanic. Indeed, in some places where such exhalations are observable, there is no trace of modern, or comparatively modern, volcanic action within considerable distances. As these exhalations are evidences of chemical action beneath the immediate surface of the earth, correct observations on their nature and the conditions under which they apparently exist become important.

a. When jets of gas escape through fissures of rocks into the atmosphere, the observer should carefully collect a portion of such gas in the manner recommended (p. 136) for the gases and vapours ejected from volcanos. He should, if circumstances permit, take a general view of the structure of the surrounding country, in order to see how far it may assist in affording information as to the cause of any gaseous exhalation under examination. Suppose, for instance, the gaseous exhalation examined should turn out to be one of car-

buretted hydrogen, and the district in which it occurred was composed of rocks containing beds of coal, there would be no very great chance of error in assuming that the gas was probably evolved from the coal-beds. Again, it having been remarked that inflammable gas often appears in the vicinity of saline springs, the observer should direct his attention to this circumstance. Salses or mud-volcanoes, as they are termed, seem the result of chemical action during which much gaseous matter is evolved. Observations should be directed to the conditions under which they occur, and particular attention should be paid to collecting the gaseous products.

b. Gaseous exhalations often bubble up through water. In this case, an observer should take a bottle (of the kinds previously noticed, p. 136), fill it with water, and then invert it with its mouth under the surface of the water through which the gas bubbles up, so as to receive the latter before it enters the atmosphere. A piece of writing-paper, or a large leaf, may be rolled up into the form of a funnel, and serve to direct the gas into the mouth of the bottle. The bottle should be then stopped or corked, and sealed in the manner previously recommended (p. 137).

c. It may be here remarked, that in collecting mineral or thermal waters, which are frequently accompanied by gas, care should be taken to collect as much of the latter as possible. Instead of bubbling up freely, the gas sometimes escapes almost imperceptibly; in which case, a bottle alone would be of little assistance; therefore a vessel having a large opening beneath should be employed, so as to offer a larger surface to the gas rising

apparatus. Such a vessel should be inverted and left with its mouth beneath the surface of the water, so that when the water which was contained in it before it was inverted, is nearly displaced by the gas, it will merely require a little dexterity in transferring the gas into bottles, the larger vessel being held beneath the water, and the gas permitted to escape from it in bubbles into the mouth of a bottle previously filled with water and inverted. In this way an observer may obtain fair results even without the aid of an apparatus especially contrived for the purpose. It is particularly important to ascertain if nitrogen be always evolved from thermal springs. Even when circumstances will not permit more than a hasty examination of a thermal or mineral spring, gas contained in the water may often be secured, if an observer fill a bottle with the least possible agitation. The bottles should be all but filled with the water, and the cement (previously noticed, p. 137) applied immediately after the cork or stopper is inserted.

XV. *Submarine forests.*—In various parts of the coasts of Great Britain, Northern France, and Germany, collections of trees of species now existing, various plants, leaves, nuts, &c. are detected at levels beneath that of high tides, frequently running out to sea, so as to be exposed only at low water. These have received the name of *Submarine forests.*

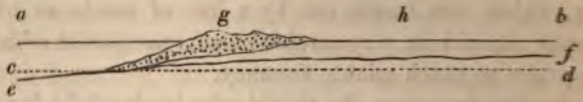
a. As some geologists consider that a change in the relative level of the land and sea in such situations is necessary to explain the facts observed, while others suppose that the trees, &c. may have grown and have

been collected in lower situations than that of high water, which was barred out by a line of beach, an observer should be very careful in an examination which requires so much minute accuracy.

In the first place, he should take levels of the locality, and see what depth, if any, the line of trees, &c. or of the submarine forest—to comprise the whole in two words—is beneath that of high or of low water, for the latter sometimes happens. He should then endeavour to ascertain if there is evidence of any portion of the submarine forest having grown on the spot where it occurs. In some cases this will be difficult; but in others he will find the roots of trees firmly planted in the ground, and the whole character of the accumulation such, that he can have little doubt that the leaves, branches of trees, &c. have been collected around the roots. We here suppose that there can be no doubt that the plants and trees are such as now exist, even in the neighbourhood, for the observer must be on his guard against similar effects which may have been produced at former geological epochs.

b. He has now to consider the general conditions of the locality, whether it be in front of a valley, of a larger tract of flat land, or otherwise. Let us suppose, for the sake of illustration, that the annexed diagram (Fig. 75) represents a longitudinal section of one of these submarine forests; *a b* being the level of high water, *c d* that of low tide; *e f*, the line of the submarine forest; *g*, a beach thrown up by the sea; and *h*, sand, silt, or clay covering up the bed *e f*. In this case the forest would alone be exposed on the shore at

Fig. 75.



low tide, and an observer would only be aware of its existence inland by artificial or natural sections which should cut through *h*. Now if roots of trees retain the places in which they grew, not only in the seaward front of the beach *g*, but also behind it, and the beach itself be found to rest upon a continuation of the forest, the beach has evidently been accumulated after the growth of the forest; and if any other beach once kept the sea away from the trees near *e*, such beach has disappeared. An observer has now to see if the beach *g* rests upon *h*; because if it does, then *g* has been accumulated after the formation of *h*. He should next endeavour to ascertain if *h* has been deposited in consequence of checks offered to the progress of fresh water charged with detritus seaward, or whether it has been produced by deposition from detritus mechanically suspended in sea-water. This observation is often difficult, except organic remains be present in *h*, when it can be ascertained whether they are of fresh-water or marine origin. In the illustration before us—which we have given because we have found it somewhat common, and not with the desire of pressing any particular views upon the reader—the order of events would be: 1. Land so situated that terrestrial plants, such as oak, yew, fir, &c. could grow, mixed sometimes with marsh plants; 2. The growth of the plants and trees, many evidently

to considerable sizes; 3. A relative change of circumstances, by which sand, silt, or mud was accumulated in a bed upon broken stumps of trees, &c.; 4. Another change of circumstances, by which the sea acted upon one side of the vegetable accumulation, laying it open beneath the level of the tides, cutting back its former covering of mud, silt, or sand, and piling up a beach which, under ordinary circumstances, bars any further attack upon that portion of the forest which remains still covered by its coating of mud, silt, or sand.

c. Correct observations on the substances, such as gravels, sands, and the like, collected above the inland portions of submarine forests, are highly valuable. Evidence is sometimes thus afforded of more than one change of the conditions which have preceded the final appearance of the submarine forest and associated beds, under the circumstances which now present themselves. Sometimes even traces of two accumulations of plants and trees may be observed, the one separated from the other by clay, sand, or gravel. An observer should be careful to notice whether there are traces of such disturbance among the vegetable remains of the forest as to lead to the supposition that there had been a rush of water over them, or whether the same remains are so disposed as to leave little doubt that the causes, whatever they have been, which have produced the effects observed, have acted in a more tranquil manner.

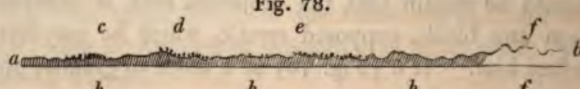
XVI. *Raised beaches.*—We have above noticed that lines of coast have been raised by earthquakes: they may be also raised in a slow tranquil manner by some general and long-continued elevation of land

position, gravity and rains, as *a* (Fig. 77) has from a neighbouring height *d*, composed of large blocks of the subja-

Fig. 77.

cent rock *c;* so that the block *a*, though it rests upon a rock differing from it, *b*, is not erratic, in the sense the term is usually employed by geologists. If, however, he finds, as in the annexed section (Fig. 78), where, for the

Fig. 78.



sake of illustration, *a b* represents a horizontal distance of twenty miles, blocks of granite resting in various situations, *c*, *d*, *e*, upon rocks, *h*, *h*, *h*, which are not granitic, there being no doubt that they could not be derived in the manner above noticed, then an observer has erratic blocks, properly so called, before him. In the above section (Fig. 78), we have supposed similar granite to that of which the erratic blocks *c*, *d*, *e*, are composed to occur in place at *f;* so that it may be concluded that the erratic blocks were derived from *f*, and now occupy their relative positions from some transporting cause.

b. We have above considered the erratic blocks to be formed of granite. It must not, however, be supposed that an erratic block is necessarily composed of that rock. Any block of rock, no matter what the composition of it may be, if it occur on another different from itself, and has not fallen from a neighbouring height by the mere effects of unequal decomposition, gravity, and rain, is an erratic block. It is obviously of importance that an observer should correctly note the composition of any erratic block, so that he may be enabled to trace it to the mass of which it once constituted a portion. When blocks of various kinds are mingled in a heap before him, he should carefully estimate the relative proportion of each kind, so that, in tracing them to their sources, he may duly appreciate the direction and amount of the forces which have thrown them into one heap.

c. As it is difficult to conceive any other power than that of moving water to have transported erratic blocks into the positions where we now find them, we should expect, if they were hurried onwards in a body, and violently thrown against each other, that they would be rounded in proportion to the respective distances they have travelled. If they have been merely iceborne upon floating and detached portions of glaciers, they may evidently have been carried considerable distances without exhibiting any other marks of friction than those which they may have experienced when falling originally on a glacier, or when brought to rest. Observations, therefore, on the angular or rounded characters of erratic blocks are essential, as also on their volume and weight; so that, when we come to calcu-

late the forces required to transport them, we may have good data for so doing. To ascertain the approximative volume or size of a block, an observer must evidently take some care, allowing for inequalities and any portion embedded in the soil. To obtain its weight, he must detach specimens which afford an average of the general structure, and ascertain the specific gravity of his specimens; after which the weight is readily calculated, the volume of the block being known.*

d. It having been found that the erratic blocks scattered on each side of the Alps diminish in volume and become more rounded as they recede from the central chain whence they were derived, an observer, if he discover erratic blocks on either side of a mountain-chain in any other part of the world, should direct his attention to this circumstance. As, in the Alps, ranges of erratic blocks are sometimes observable in a line some height above the bottom of a principal valley, through which they have evidently descended, this circumstance also should not be neglected. If the annexed sketch (Fig. 79) represent a principal Alpine valley, then a line of erratic blocks sometimes occurs as at *a*, while accumulations are occasionally found behind an elevation which is open to the line of valley, such as *b*, and where we may consider that an eddy would be produced if a considerable volume of water suddenly descended the valley. An observer should also direct his attention

* Suppose an observer finds the specific gravity of the rock to be 2·66; then as a cubic inch of distilled water weighs 252·458 grains, 252·458 × 2·66 = 6715·383 grains, the weight of a cubic inch of the rock. Having ascertained the weight of a cubic inch of any rock, that of any number of cubic feet can of course be readily obtained.

to any face of a mountain which may arrest the progress of such a volume of water in its passage down the valley, and see whether erratic blocks are there collected; and if so, whether they occur mixed pell-mell of all sizes, down to mere gravel.

Fig. 79.

e. Over extensive tracts of comparatively level country where erratic blocks occur, an observer should endeavour to trace the lines which the various kinds of rocks may have travelled. He can in some manner accomplish this by adopting particular colours for the different rocks, and marking on a map, by such colours, the lines on which he discovers such rocks. If the courses of that multitude of erratic blocks which occurs in Northern Europe and America were thus traced, even approximatively, much valuable information would be obtained. If this were done, we should find many colours

running short distances up to the parent rocks whence the blocks were derived, while others would extend across considerable areas. Some lines, though often curved in the small scale, would take given directions on the large; while many smaller lines would follow various directions.

f. It is important to note the relative age of the rock upon which erratic blocks rest, if the observer be sufficiently versed in geology: if not, he should carefully detach specimens from it, — ascertain whether it contains organic remains or not: if it does, he should collect as many of them as he can; mark whether the beds, should the rock be stratified, are horizontal or not; and, above all, he should examine whether there are any evidences of the block having been encased in sands, marl, or clay, which having been removed by surface causes, has left the block exposed. It is considered that the blocks generally are superficial, and have not been covered by any body of transported matter, constituting a bed covering a large area, and to which some name, marking a particular geological epoch, has been assigned. It is therefore particularly necessary to pay attention to this point.

g. The observations on erratic gravel should be much the same as on erratic blocks. Great care should be taken to examine the kind of pebbles of which any mass of gravel covering an extensive district may be composed. It is obviously important duly to appreciate the causes which have produced their transport: whether they have been gradually detached from their parent rocks, and slowly transported by the aid of rivers or other aqueous agents, now daily in force, or

whether we must look to any more general action of moving water passing in greater volume over the land. When accumulations of gravel are only composed of pebbles that may have been carried down the valley in or at the termination of which they are found, the size, shape, and weight of the pebbles should be taken into account, and a fair estimate made of the power of the waters, now descending the valley, to carry them down, proper allowance being made for the slope of the river-channel, and the accumulative power of floods during a succession of ages. It should also be seen whether pebble-beds are, such as the celebrated Crau district (France), mere terminations of a great wash of erratic blocks. In some situations, gravels of different kinds rest upon each other; one having been formed by the action of rivers, another probably from the passage of a larger body of water:—this should receive careful attention. Again, though gravel-beds may appear superficial at one place, they may be only lower portions of a series of rocks, which can be traced beneath many others in another; a conglomerate bed having been weathered, the cementing matter removed and the pebbles left. It is necessary, therefore, that the observer pay attention to this circumstance.

XVIII. *Ossiferous caverns and osseous breccia.*—Ossiferous caverns are caves so named because in them the remains of various animals, such as bears, hyenas, elephants, &c. are detected, often enveloped by mud or other deposits, and in such cases concealed from ordinary observation. Osseous breccias are for the most part clefts of rocks, such as have been previously noticed (p. 110), filled with bones, fragments of rocks,